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THE FRENCH ROOF TRUSS.

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THE French Roof Truss is one of the most popular forms in use. Its economic proportions and its beauty are both in its favor, and conspire to give it a place among the leading forms of roof trusses. The roofs of some of our most spacious and elegant railway station buildings are supported by this truss. Over our machine shops, foundries and industrial works of all kinds, it may be seen; and it quite as frequently spans the walls of the college or the public hall.

The analysis of this truss becomes, therefore, of special importance, though it has been generally, at least partially, neglected, or erroneously treated, by writers on bridges and roofs. Some have given results wide of the truth, others results more nearly correct. Some have given a partial analysis only, others none at all. On one point many agree: that the case is a simple one, and can be safely left to the student himself. In a treatise, perhaps in the hands of more architects than any other, the treatment of this truss is erroneous in several respects and in a marked degree. A brief description of the truss will suffice.

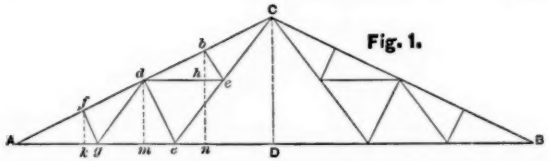

Fig. 1.

AB is the long tie and AC and BC the main rafters. AC is supported at d by the inverted king-post AeC, in which the post de is perpendicular to AC, and extends to AB. Ae and Ce are the tie rods. The tertiary trusses Agd and deC are added. The arrangement of the parts and pieces is apparent from the figure.

NOTATION.

Let W = total load on the roof.

$\frac{W}{N} = p$ = load at each of the joints b, d, f, etc.

V = reaction at A = $\frac{1}{2}$W = $\frac{1}{2}$Np = 4p.

AD = s, AC = l and CD = d.

t_1, t_2 and t_3 = tension on De, eg and gA respectively.

c_1, c_2, c_3 and c_4 = compression on Cb, bd, df and fA respectively.

ANALYSIS.

I. The load at b is sustained directly by bc and bd, and we have:

Strain on

$$bc = p\frac{AD}{AC} = p\frac{s}{l} \quad . \quad . \quad . \quad (1)$$

$$bd = p\frac{CD}{AC} = p\frac{d}{l} \quad . \quad . \quad . \quad (2)$$

and the same equations apply to fg and fA.

Furthermore, the strain on $bc\left(=p\frac{s}{l}\right)$ causes strain on Cb, bd, Ce and cd, which strains, according to the principles of the king-post truss are:

Strain on

$$Cb \text{ or } bd = \tfrac{1}{2}p\frac{AD}{AC}\times\frac{Cb}{cb} = \tfrac{1}{2}p\frac{\overline{AD}^2}{CD.AC}$$

$$= \tfrac{1}{2}p\frac{s^2}{dl} \quad . \quad . \quad . \quad (3).$$

And the same on df or fA from the strain on fg.

Strain on

$$Ce \text{ or } cd = \tfrac{1}{2}p\frac{AD}{AC}\times\frac{Ce}{bc} = \tfrac{1}{2}p\frac{AD}{AC}\times\frac{AC}{CD}$$

$$= \tfrac{1}{2}p\frac{s}{d} \quad . \quad . \quad . \quad (4).$$

And the same on dg or gA from the strain on fg.

Again the strut de sustains one half the pressures or loads at b and f, and $p\frac{AD}{AC}$ directly from the load at d.

Hence, strain on

$$de = 2p\frac{AD}{AC} = 2p\frac{s}{l} \quad . \quad . \quad . \quad (5).$$

This pressure on de gives, according to equations (3) and (4):

Strain on

$$Cd \text{ or } dA = p\frac{AD}{AC}\times\frac{Cd}{ed} = p\frac{AD}{AC}\times\frac{AD}{CD}$$

$$= p\frac{s^2}{dl} \quad . \quad . \quad . \quad (6)$$

$$Ae \text{ or } eC = p\frac{AD}{AC}\times\frac{Ce}{de} = p\frac{AD}{AC}\times\frac{AC}{CD}$$

$$= p\frac{s}{d} \quad . \quad . \quad . \quad (7).$$

TOTAL STRAINS.

From (1) strain on bc or fg $= p\frac{s}{l}$ . . . (1)

" (5) " " de $= 2p\frac{s}{l}$ . . . (5)

" (4) " "cd or dg $= \frac{1}{2}p\frac{s}{d}$ . . . (4)

From (7) strain on ec $= p\frac{s}{d}$ . . (7)

" (4) and (7) " " eC $= \frac{3}{2}p\frac{s}{d}$. (8)

To find tension t_1 on De, consider AB severed at D and take moments about C. We have:

$$t_1 d = Vs - V\times\tfrac{1}{2}s = \tfrac{1}{2}Vs = 2ps. \therefore t_1 = 2p\frac{s}{d}$$

. . (9)

Now (7) + (9) gives strain on

$$eg = t_2 = 3p\frac{s}{d} \quad . \quad . \quad . \quad (10)$$

Also (4) + (10) gives strain on

$$gA = \frac{7}{2}p\frac{s}{d} \quad . \quad . \quad . \quad (11)$$

Strain on Af = strain on

$$gA\frac{l}{s} = \frac{7}{2}p\frac{l}{d} \quad . \quad . \quad . \quad (12)$$

And observing that the strain on any section of the rafter exceeds the strain on the adjacent section above by $p\frac{d}{l}$ given by (2) we have:

Strain on fd = $\frac{7}{2}p\frac{l}{d} - p\frac{d}{l}$ . . . (13)

" " db = $\frac{7}{2}p\frac{l}{d} - 2p\frac{d}{l}$ . . . (14)

" " bC = $\frac{7}{2}p\frac{l}{d} - 3p\frac{d}{l}$ . . . (15)

II. We may first find the strain on the upper section of the rafter, then on the other sections by addition, and on the other members of the truss as before.

From the truss Ccd strain on

$$Cb = \tfrac{1}{2}p\frac{s^2}{dl} \quad . \quad . \quad . \quad (16)$$

From the truss CeA strain on

$$Cb = p\frac{s^2}{dl} \quad . \quad . \quad . \quad (17)$$

The $\frac{1}{2}p$ at C gives by equation (2) a strain on

$$Cb = \tfrac{1}{2}\frac{d}{l} \quad . \quad . \quad . \quad (18)$$

And besides these, there will be compression also on Cb due to the thrust at C, the same as though the rafters were not trusses.

Let H in Fig. 2=the horizontal thrust at C, and L the component of that thrust in the direction of CA. Then:

$$H\times CD=\tfrac{1}{2}W\times\tfrac{1}{2}AD=\tfrac{1}{4}W\times AD$$

$$\therefore\ H=\tfrac{1}{4}W\frac{AD}{CD}=2p\frac{s}{d}$$

$$L=2p\frac{s}{d}\times\frac{s}{l}=2p\frac{s^2}{dl}\quad\ldots(19)$$

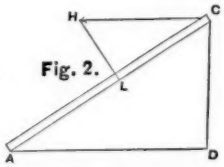

Fig. 2.

Now adding (16), (17), (18) and (19) we have compression on

$$Cb=\tfrac{1}{2}p\frac{d}{l}+\tfrac{1}{2}p\frac{s^2}{dl}$$

$$=\tfrac{1}{2}p\frac{d}{l}+\tfrac{1}{2}p\left(\frac{l}{d}-\frac{d}{l}\right)$$

$$=\tfrac{1}{2}p\frac{l}{d}-3p\frac{d}{l}\quad\ldots\quad(15)'$$

which is the same as (15).

III. The case is readily solved by moments. To find strain on De consider De severed and take moments about C; and similarly for eg taking moments about d, and for gA about f. Hence:

$$t_1=\frac{\frac{1}{2}ps-p\times\frac{3}{4}s-p\times\frac{1}{2}s-p\times\frac{1}{4}s}{d}$$

$$=2p\frac{s}{d}\quad\ldots\quad(9)$$

$$t_2=\frac{\frac{1}{2}p\times\frac{1}{2}s-p\times\frac{1}{4}s}{\frac{1}{2}d}=3p\frac{s}{d}\quad\ldots\quad(10)$$

$$t_3=\frac{\frac{1}{2}p\times\frac{1}{4}s}{\frac{1}{4}d}=\tfrac{1}{2}p\frac{s}{d}\quad\ldots\quad(11)$$

To find strain on $cd(=dg)$ consider dg severed and take moments about b. We have:

Strain on $cd\times bh=\frac{1}{2}p(\text{at } d)\times dh$

$$\therefore\ \text{Strain on } cd \text{ or } dg=\tfrac{1}{2}p\frac{dh}{bh}=\tfrac{1}{2}p\frac{s}{d}\quad\ldots(4)$$

Strain on ec=strain on eg−strain on De

$$=3p\frac{s}{d}-2p\frac{s}{d}=p\frac{s}{d}\quad\ldots(7)$$

Strain on eC=(4)+(7)

$$=\tfrac{3}{2}p\frac{s}{d}\quad\ldots(8)$$

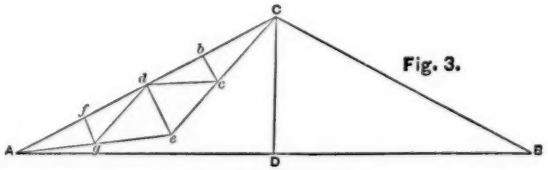

Fig. 3.

To find strain on Af or fd take moment about g. Hence:

$$c_4=\tfrac{1}{2}p\frac{Ag}{Af}=\tfrac{1}{2}p\frac{l}{d}\quad\ldots\quad(12)$$

$$c_3=\tfrac{1}{2}p\frac{Ag-pkg}{fg}=\tfrac{1}{2}p\frac{l}{d}-p\frac{d}{l}\quad\ldots\quad(13)$$

To find strain on db and cd severed and take moments about e. Hence:

$$c_3\times de-\tfrac{1}{2}p\frac{s}{d}\times\tfrac{1}{2}d=\tfrac{1}{2}p\times Ae-p\times ke$$
$$-p\times me.\quad\ldots\quad(\text{See } 4).$$

or

$$c_2\times de-\tfrac{1}{4}ps=\tfrac{1}{2}p\times Ae$$
$$-2p\times me-p\times km=$$
$$\tfrac{1}{2}p\times Ae-2p\times me-\tfrac{1}{4}ps$$

$$\therefore\ c_2=\tfrac{1}{2}p\frac{Ae}{De}-2p\frac{me}{de}=\tfrac{1}{2}p\frac{l}{d}-2p\frac{d}{l}=\ldots(14)$$

and similarly for the strain on bC.

Or strain on bc=strain on bd−(strain on fd−strain on bd)

$$=\tfrac{1}{2}p\frac{l}{d}-3p\frac{d}{l}\quad\ldots\quad(15)''$$

the same as (15).

The parallelogram of forces, the general equations of mechanics, or any other means of effecting the solution would yield the same results which we must conclude are correct.

In case the strut de does not extend to the tie-rod AB, the strains will be somewhat modified. On the struts and long tie the strains will be the same as in the preceding case. On the tie rods they will be greater because the trusses Agd, AeC, etc., are lower. The same equations, however, apply.

Thus the strain on Cb or bd, through

bc, and on dt or fA, through fg, is given by equation (3) and

$$=\tfrac{1}{2}p\frac{AD}{AC}\times\frac{Cb}{bc} \quad . \quad . \quad . \quad (3)'$$

which is greater than in the preceding case since bc is smaller. Similarily the strain on Ce or cd, through bc, and on dg or gA, through fg, is given by equation (4) and

$$=\tfrac{1}{2}p\frac{AD}{AC}\times\frac{cC}{cb} \quad . \quad . \quad . \quad (4)'.$$

This is the total strain on cd or dg.

Strain on Cd or dA, through de, is given by equation (6) and

$$=p\frac{AD}{AC}\times\frac{Cd}{ed} \quad . \quad . \quad . \quad (6)'$$

And the (total) strain on ce or eg, through de, is by equation (7):

$$p\frac{AD}{AC}\times\frac{Ce}{de}=p\frac{AD}{AC}\times\frac{cC}{cb} \quad . \quad . \quad . \quad (7)'$$

Total strain on cC or gA = (4) + (7)'

$$=\tfrac{3}{2}p\frac{AD}{AC}\times\frac{cC}{cb} \quad . \quad . \quad . \quad (8)'$$

The strain on Cb due to the load at C, as well as that due to the thrust at C, is the same as in the preceding case; and the strain due to the small trusses is given by equations (3)' and (6)'. Hence adding (3), (6), (18) and (19) we have:

Strain on

$$Cb=\tfrac{3}{2}p\frac{s}{l}\times\frac{bC}{bc}+\tfrac{1}{2}p\frac{d}{l}+2p\frac{s^3}{dl} \quad . \quad . \quad . \quad (15)'$$

The strain on bd exceeds this by $p\frac{d}{l}$ and on df by $2p\frac{d}{l}$, and on fA by $3p\frac{d}{l}$.

EXPLOSIONS AND EXPLOSIVES.

From "The Builder."

As the shadows of evening close over a modern city, a sense of quiet, to some extent, replaces the busy activity of the day. Those inhabitants who, from daybreak or from, at least, an early hour in the morning, have been actively engaged in the pursuit of their daily occupations, gather round the domestic hearth, share the evening meal, and prepare for the well-earned repose of the night. The student hails the comparative quiet, and renews his study. Among the more wealthy and leisurely classes the attraction of the dinner-table, of the drawing-room, or of the theaters, commences, and the life of pleasure finds its noon. Rest, amusement, and calm study divide the time.

If, at this period of the day, a sudden blow, like that of hammer wielded by a giant, strike the house,—a blow followed by the immediate extinction of gaslights, and the tinkling sound of falling and shivering glass, to the effect on the nerves is one not easily forgotten. Having experienced that effect more than once or twice, and that from very different causes, we can form some conception of the effect produced on the inmates of the Winter Palace at St. Petersburg, by the explosion of a charge of dynamite in the guard-room shortly after nightfall on the 17th of February.

There are four sources from which sudden explosive shocks occur; and it so happens that we have had some close experience of three out of the four. Of the effect of a bombardment, the most alarming of all, from its persistency we cannot speak with this experience, having only heard the sullen thunders of such an attack from a safe distance on the spurs of the Apennines. But with explosions of gunpowder, sudden outburst of volcanic energy, and earthquake, we have direct acquaintance. Of these the most terrific is the earthquake; as the utterly illimitable power that is behind even the feeblest shock impresses the imagination, or, at all events, the emotional feeling, with a very solemn terror. But the most startling are the explosions into which human agency enters, whether it be that of gunpowder and kindred matter, of gas, or of steam.

In the case of the explosion, within the precincts of a populous town, of a large quantity of gunpowder or of any similar substance, an additional terror is caused if it occur by night. There is

not only that sense of unpreparedness for any sudden call on the energies to which we before alluded, but there is the added terror of sudden darkness. The instant extinction of gas is a usual consequence of an explosion of a certain force. Other lights, as far as our experience goes, are unaffected, unless incidentally, by such a shock. But over a large area of ground every gas-lamp in the streets, and within certain limits all those in the houses, are immediately put out. The reason no doubt is that there is a sudden pressure exerted by the atmosphere, which drives back the gas into the pipes; and the momentary cessation of the flow, of course, puts out the light. It must be remembered that a pressure equal to that of a column of about half an inch of water is all that can be placed on issuing gas without great loss of light. This pressure is very much less than that suddenly impressed on the atmosphere, and communicated to a very great distance from the center of explo sion, by the sudden development of a large volume of explosive gas. Here is, therefore, a danger apparently inseparable from the use of gas as a source of illumination in any locality subject to explosions.

A second danger, of course, follows from the extinction of gas. Every jet continues to pour forth its stream of unconsumed combustible vapor. Happily, in this case, the foul smell, which is one of the disadvantages of gas, is in itself warning of the pressure of the dangerous element, and serves to lead the careful housekeeper to the source of danger. But in a large building, such as a theater, unless there be in command some one of sufficient presence of mind at once to cut of the main supply, an explosive mixture would very soon be formed, and the consequences would be not only alarming, but disastrous. In one of the explosions above referred to, that of the *Carlo Terzo* frigate, in the harbor of Naples, in the winter of 1856–7, the great theater of San Carlo was full of its usual Sunday company at the moment of the explosion, which was about 11:30 p. m. The gas-lights in the theater, as well as those in the streets and houses, were at once extinguished by the explosion. It is to be presumed hat some ope had the presence of mind to attend to the main. The building is one of the largest theaters in Europe, and the heat, when the house is full, is intense, especially in the upper galleries. The first thought of every one was how to get out. But for the fact that wax torches are burned as well as gas on the more important occasions in this theater, the terror which was actually felt might have been attended by a worse catastrophe.

There is thus in all houses where gas is consumed the added danger of subsidiary explosions that ensues on any great shock, such as those of which we have just spoken. But the sudden darkness that follows the blow is not all that adds terror to the scene. The same action that extinguishes the gas forces the glass of the windows from their frames. The fragile material is not strong enough to resist the sudden pressure over its whole surface. We are not aware that any calculations have been made either of the resisting power of glass to pneumatic pressure, suddenly applied, or of the pressure developed over a given area by the explosion of a given weight of powder. But we can speak from actual experience as to the effect. Our readers may remember the damage done to windows, and even to doors, by the explosion on the Regent's Park Canal, not so very long ago. On two occasions at Naples, that of the explosion of the powder magazine at the Port, and that of the *Carlo Terzo* (which occurred within a few weeks of one another), the destruction of glass within a radius of 1,000 or 1,500 yards was total. Not a window was left looking on the street for a considerable distance from the centers of explosion. It might have, perhaps, been anticipated that the windows would have been blown inwards. But, in point of fact, the panes of glass fell out on the balconies or on the pavement, which was immediately covered, for miles in extent if all the streets were measured, by a fine white shining gravel, consisting of pulverized glass.

To the terror of darkness and of the sound of breaking glass will be added a thousand other elements of terror which do not come within the province of the builder or the engineer to describe.

With a great mass of people the idea that the end of the world has come will

be found to be prevalent. This kind of terror is probably more common in countries where earthquakes and volcanoes are unknown, as the occasional sudden outburst of these great natural energies gives a sort of education to those who are exposed to them,—an education as to the possible occurrence of unexpected shocks, of which the inhabitants of districts not subject to these great meteoric disturbances are—perhaps we ought to say happily—destitute. Then comes the terror of evil men. Revolution is the first thought, often incorrectly feared. But the readiness with which those classes which prey upon their more wealthy fellow citizens will be likely to avail themselves of the facilities afforded by sudden darkness, and the partial destruction of the usual defences of the dwelling-house, is likely to depend chiefly on the fear with which they are themselves impressed. If there was any ground known to these people for anticipating an explosion, they would probably have prepared themselves for taking full advantage of the terror which it would be likely to spread.

These remarks have been suggested by the accounts that have excited so painful an interest in this country of alarming recent explosions. The attention of men of science, and, to a certain extent of the public, has been directed to the subject of explosive mixtures of late, partly by the great progress made in the improvement of artillery, and partly by the kindred advance made in the construction of torpedoes. We are as yet without a unit of explosive power. We can compare one substance with another, and we can compare one weapon with another. But it is only by this sort of rule-of-thumb measurement that we can as yet in any way predict the effect of an untried mixture, or an untried method of applying it. A range of eight miles has been attained by a projectile, and by enlarging the chambers and elongating the muzzle of our guns, the muzzle volocity attained is continually on the increase. The torpedo is, virtually, a movable mine, and torpedoes have been used in American waters containing as much as a thousand pounds of gunpowder. A regular torpedo service was organized during the war.

There is one consideration, we can hardly say of comfort, but yet to a certain extent pointing in that direction, attaching to the recent atrocious attempts at destruction in Russia. That is, that no artillerist, engineer officer, or man practically familiar with the legitimate use of explosive substances, has had any visible hand in them. It will be obvious why we employ a certain reserve in referring to this point. We cannot allow our pages, however indirectly, to give any hints that might be used for a mischievous purpose. But this we may safely say, the effect of the explosive force has been in each instance wholly inadequate to the cost and risk (to speak of nothing else) incurred in making the preparations for the explosion. This has been due, not so much, we think, to the employment of an insufficient quantity of dynamite or other explosive material, as to an ignorance of the rules which, happily for society, control the action of all explosive force. At the same time, there can be no doubt that the estimate of the quantity of dynamite exploded in the Winter Palace is a gross exaggeration; 126 lbs. of this substance, which is the quantity mentioned in the telegrams, would be equal in explosive force to more than thirteen barrels of powder, an allowance sufficient for blowing up, not a room only, but a magazine. It is probable that some error was made by the reporter, for it was added General Todleben said that if 10 lbs. more of the explosive material had been used, the effect would have been wholly ruinous. The addition of the latter quantity to the former would have only added 16 per cent. to the explosive power (the respective forces being as 15,876 to 18,496;) and no engineer would pretend to speak with certitude within so small a limit, unless he knew the exact facts, which have, in this case, of course been veiled by the explosion.

Those of our readers who are artillerists will fully understand our reference, and will agree with the only rational deduction. Those who are not, will be better content to take our opinion as it is offered, than to ask for that further information of which mischievous use might be made. But it is interesting to trace the difference between the results of the information which can be obtained

from books, and that which is learned in a practical apprenticeship. No doubt the difference is on the decline, but yet we may anticipate that it will never wholly disappear. We see that the executors of these mischievous projects have made themselves acquainted with the progress of scientific discovery. They have learned what explosives are the most compact and manageable. They have acquainted themselves with the infernal ingenuity of the "Thomas clockwork machines." They have learned how to arrange the wires, and how to work the electric battery. Here they stop; and it is some comfort for society to see that the amateur destroyer betrays the want of practical training. None the less do we feel convinced that the magnitude of the charges has been overstated. We doubt if the explosion, even in the open air and in an open space, of anything like 120 lbs. of dynamite would leave a pane of glass in a window within half a mile, or a larger radius. By the explosion of a few cans of nitro-glycerine on the wharf of Aspinwall, in 1866, a considerable portion of the town was destroyed, shipping at some distance in the harbor was much damaged, and a number of lives were lost. An explosion of a storehouse containing some hundreds of pounds of nitro-glycerine took place at Fairport, Ohio, in 1870, accompanied by much loss of life. The shock was felt at Buffalo, 160 miles distant.

Dynamite is a substance which was invented in 1867 by Nobel, with the idea of producing an explosive for mining purposes which should be less dangerous to handle than nitro-glycerine. It consists of three parts nitro-glycerine and one part infusorial silica, or porous earth. The presence of the silica renders the powder less liable to explode from concussion. The above is the true dynamite, but the word is used as a generic name for other mixtures of nitro-glycerine, such as colonia powder, which is gunpowder, with a mixture of 40 per cent. of nitro-glycerine; dualine, which contains from 30 to 40 per cent. of nitro-glycerine mixed with sawdust saturated with nitrate of potassia; and litho-fracteur, which contains 35 per cent. of nitro-glycerine mixed with silica, and a gunpowder made with nitrate of baryta and coal.

The explosive energy of nitro-glycerine is given at from four to thirteen times that of rifle-powder,—a wide margin. M. Berthelot gives, in the "Annales de Chimie et de Physique," a table showing the relative force of explosives. Of these, gun-cotton mixed with chlorate is the most formidable, next to nitro-glycerine, which is calculated at 6.78 times the force of powder used by the sportsman. This powder is somewhat stronger than that used for cannon, and is as 1 to 633 compared with that used for mines. That not only competent experience, but calm courage, is necessary for any certainty in dealing with these terribly dangerous materials, there can be no doubt. It may well be questioned whether perfect freedom in the manufacture, sale, and transport of such substances is consistent with national safety. It is not difficult to manufacture nitro-glycerine; but those who attempt to do so with anything of the secrecy of the smuggler are dealing with danger. Their lives are in their hands; and not only so, but the danger to their neighbors is very great. Society should demand that every guarantee for safety should be given by any persons who are engaged in these delicate and dangerous operations. Even with all the precautions that are taken in the manufacture of gunpowder, either by the Government or by well known and respectable manufacturers, scarcely a year passes without a fatal explosion. If such be the risk attending the manufacture of a substance so comparatively inert as gunpowder, which is not liable to ignite by concussion or by pressure, what must be that attendant on every stage of the production, stowing, transport, and use of a composition of the terribly unstable nature of any nitro-glycerine explosive?

In speaking of the evidence of the absence of an educated artillerist or engineer on the two occasions of the explosion under the Moscow Railway, and that at the Winter Palace at St. Petersburg, we must not be understood as in any way underrating the terrible gravity of the situation. It is not in these columns that we have any political opinions to express. But the existence of society is a matter above all politics. The safety of the fireside is only to be endangered by those who deserve the title of

enemies of the human race. Even as we write the electric wires bring intelligence of the discovery of an infernal machine at Constantinople. Dynamite and bombs have been, it is said, found, which it is supposed were intended to be used against the Sultan. And we must remember that the more rude and inexperienced the hands into which such terrible agencies are put, the greater the danger to the public at large. The use of petroleum at Paris, under the frantic reign of the Commune, was to a great extent committed to women. The term "*pétroleuse*" thus passed into the French language. If there is any form of human crime and madness which more revolts the instinct of the architect, or of all those who are interested in the grandeur and stability of our public monuments, or the tranquility and security of the domestic abode, it is this new outbreak of destructive frenzy. Not only has there been an unsparing use of means of destruction, in which human life has been struck at, and the cost of any material mischief has been disregarded, but there has been the direct attempt to produce terror by attacking palaces, houses, and public buildings. Fire is called in to complete the ravages of gunpowder. The number of fires that have of late been reported as occurring in Russia is such as to point to the great improbability of their being the work of accident or of carelessness. That for the last few weeks we have heard little of such conflagrations by no means shows that they have ceased.

It is true that these outbursts of human malevolence are as nothing when compared to the overwhelming might of the earthquake. Within a few months of the time when Naples was shaken by the two explosions above referred to, the city was also subjected to a night of earthquake, in which, after the first sudden and terrible shock, as many as thirty-six smaller shocks succeeded. Hardly an individual in Naples passed that night in bed. The squares and public places were filled, the churches were besieged by throngs of terrified suppliants. But the damage actually done in the city was small. Campania was only on the fringe of the earthquake. In Basilicata the number of churches and houses thrown down was very large, and 30,000 people are said to have perished on that night in that province.

The great contrast that exists between the narrow range of the directly destructive energy of explosives, and the wide area shaken by an earthquake may be referred to as a comparative mitigation of the terror inspired by the human mechanism. It is a relief to the mind to turn for a few moments to the contemplation of the use of the torpedo for the direct service of mankind. In the petroleum regions of the United States nitro-glycerine has been introduced into some of the exhausted oil-wells, and exploded at great depths beneath the surface, with the intent of opening fissures that should tap fresh supplies of oil. Cartridges of 25 in. and 35 in. long and 5 in. diameter were prepared, and lowered into the bore-holes until they were opposite the mud-veins known to exist at certain levels. They were then exploded by electricity, arranged to run through copper wires. The method has been protected by patent, and is said to have restored productiveness to many exhausted wells.

A smile may be excited at an application of cartridges of "gravel powder" to what the Americans politely call trout-fishing in the Rocky Mountains, but which we most brand as unmitigated poaching. Of course it is one thing to try to kill fish for food, where food is only to be obtained by the chase, and another to enjoy the sport of the angler. A cartridge of gravel powder, containing about a quarter of a pound, is dropped into any deep hole in the river supposed to be haunted by fish, and exploded by a fuse. It kills or stuns all the fish within a radius of 30 feet or 40 feet, and they are captured as they float to the surface. We commend this sub-aquatic infernal machine to the condemnation of all true sportsmen; even as we denounce the resort to the murderous force of explosives whenever they are employed without the most distinct ground of justification.

THE BEST ROUTE FOR A LINE OF RAILWAY TO INDIA.

By B. HAUGHTON, C. E.

From the "Journal of the Society of Arts."

THE first sod of that railway has been already cut which is the subject of this paper, and which I have ventured to call "a line of railway to India." The act has taken place at the Indian terminus, at Shikarpore, on the Indus, the point of its junction with the Indus Valley Railway. The line owes its inception to the war now being waged in Afghanistan, and to the pressing necessity for pushing our troops and their *impedimenta* into the enemy's country. It is called in India "the Candahar Railway," and it is said that, in January last, it had reached its 139th mile, near the south end of the Bolan Pass. The city of Candahar is 350 miles, and Herat is 650 miles, from the terminus. It is almost certain that Candahar will be reached before the close of the current year, and without doubt no time will be lost in the extension to Herat "the key of India."

The subject of a railway to India has been discussed over and over by some of the most active, thoughtful, and enlightened men of the age. I cannot, therefore, hope to do much more than bring forward an old subject, dressing it in somewhat of a new garb, at a period when it has certainly obtained new attractions and a new value, owing to political changes that have occurred; to the additional light that has been thrown on it as the years roll on; and owing to the circumstances that it is an essentially progressive subject.

In preparing this paper, I have to express my indebtedness to those great masters of the question who have lived, and worked, and traveled, in the parts concerned, some of whom have written much upon it—viz., General Chesney, Sir Henry Rawlinson, Mr. William Patrick Andrew, Mr. T. R. Lynch, Sir Bartle Frere, Sir Rutherford Alcock, Lord Stratford de Redcliffe, Lord Sandhurst, Lord Strathnairn, General Sir Arnold Kemball, Rev. James Long, Von Hochstetter, the President of the Geographical Society of Vienna, Sir John Mac Neill, C. E., Mr. Ainsworth, Captain Jones, Captain Charlewood, and others, several of whom have so thoroughly illuminated the subject by their evidence, given before the Select Committee of the House of Commons, in 1871-2, a committee which sat under the distinguished chairmanship of the present Chancellor of the Exchequer.

For myself, I may say that my interest in the question arose on that memorable 13th of October, 1869, when, thanks to the hospitality of his Highness the Khedive of Egypt, I stood on the forecastle of one of his despatch boats, the *Fayoum*, and watched the procession of the ships as they filed past into the "maritime canal of Suez," and on board of which many of the nations of Europe were represented by their emperors and princes, headed by the Empress of the French, in her yacht *L'Aigle*, followed by the Emperor of Austria, and the King of Prussia. England, conspicuous by the absence of any royal deputy, was unofficially visible in the person of the Admiral of the Mediterranean fleet, who steamed through the Canal gaily in his yacht, the *Deerhound*. Lord Houghton and Lord Alfred Paget, Sir John Hawkshaw, C. E., and Mr. Bateman, C. E., Mr. Gregory, M. P., Mr. Pender, M. P., Mr. Ramsay, M. P., were there. Liverpool was represented by Mr. Charles Clarke, president of the Chamber of Commerce; Manchester, by Mr. Grave, Mayor, and Sir John Bennett, chairman of the Cotton Supply Association. Glasgow, Edinburgh, Birmingham, Sheffield, and Bristol also were represented; Mr. W. H. Russell and many members of the Press were there; while four British ironclads added a certain picturesque effect to the scene, as they lay at anchor in the offing.

The witnessing of such a remarkable assemblage and brilliant pageant, having for its stage Egypt and the newly excavated maritime Canal of Suez, was sufficient to leave an ineradicable impression

on the mind as to the importance of the occasion, and the magnitude of the issues bound up in the existence of this famous waterway; and that importance has not been diminished after ten years' experience of its working, and the near one million of pounds sterling of gross revenue that it now returns per annum to its proprietors.

The common conversation, then, amongst our countrymen was this:—"The next event will be the construction of a railway to India by England, how soon, and what is to be the route?" These questions are, on the whole, still unanswered.

Several rival schemes are in the field—unless it may be that the commencement of the construction of the Candahar Railway has decided the line of country that is to be taken up. It sometimes happens in affairs, that when men hesitate in taking a side, and delay in carrying out an enterprise, the force of circumstances steps in and proclaims their inefficiency by deciding for them, and in spite of them. Of these several schemes I shall not now attempt to consider more than two, viz.: first, that of General Chesney and Mr. William Patrick Andrew, *via* the Euphrates Valley and the Mekran coast to Kurrachee, which may be called "the South Persian route;" and, second, that which I more particularly advocate, or "the North Persian route."

The western terminus of the latter line will be at Constantinople, and its eastern terminus at Shikarpore, on the River Indus, about 250 miles in a straight line N. N. E. from the port of Kurrachee. It is impossible, at this stage of the matter, to settle the route from Constantinople through Asia Minor; several directions are suggested for it. Those most in favor seem to be two; that *via* Ismid, Angora, Sivaz, and Arabkir; and a more westerly route *via* Ismid, Karahissar, Konieh, Karabunar, and the Cilician gates. The center of Asia Minor consists of high table land, throwing out ridges and spurs on all sides; it is a rough and difficult country, and is divided from the valleys of the rivers Euphrates and Tigris by the Taurus range of mountains, about which little appears to be known. Mr. Lynch has, however, stated in evidence that Mr. Consul Taylor has discovered a perfectly practicable pass for a railway at Arabkir.

In addition to the terminus at Constantinople, the railway will have a second western terminus, the site of which will be on the coast of Syria, from which point a branch line will be carried to join that from Constantinople, or, in other words, the railway will bifurcate at a point to be named on the southern slopes of the Taurus range, one fork leading from Constantinople, the other from the Levant. The absolute necessity of this last mentioned fork is universally conceded, in order that England may always possess a free and undominated approach to the railway from the open sea; and, indeed, one cannot help coming to the conclusion that the Government, in gaining the island of Cyprus, had for the principal object of its acquisition to protect the Levant terminus, which will be just 130 miles from the harbor of Famagosta in the island.

The port of Swadia, on the Levant, seems to possess advantages as a point of departure superior to those of any one of the other ports recommended. The second fork, then, will commence at Swadia, will pass through the towns of Antioch, of 10,000 inhabitants, and Aleppo, of 70,000; it will cross the Euphrates, between Biredjek and Port William, the latter being the point where Chesney built up his squadron and launched it, having dragged it and all the rest of his *materiel* overland from Swadia; here the river is about 250 yards wide and 15 feet deep; the railway will then run along the slopes of the Taurus, not far south of the towns Orfah, Diabekir, Nisibin, and Mardin, and will intersect the various roads leading south from Asia Minor into Mesepotamia, a most valuable factor in the position. It will then tap that great center of the traffic of a large tract of country, and of population, the city of Mosul, resting on the right bank of the river Tigris, adjacent to the ruins of the ancient city of Nimroud, the scene of Sir H. A. Layard's discoveries; it will cross the Tigris south of the junction of the Greater Zab with that river, pass on by or near to the town of Erbil, cross the Lesser Zab, pass near the towns of Kirkuk and Kefri, where it is 90 miles from

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Baghdad, "the City of the Caliphs," and which, by virtue of its large population, extensive trade, and commanding riparian situation, will be worthy of a branch line of that length. At Kefri, it finds itself close to the Persian frontier, and face to face with the "Gates of Zagros," a range known to Sir Henry Rawlinson, which it will cross at a point to be determined. The first town of note met with in Persia, is Kirmanshah; it then passes through Hamadan, which those persons who have read Lord Beaconsfield's "Tale of Alroy," will recollect, and shortly after reaches Teheran, the capital, due south of the axial line of the Caspian Sea, and from the point of view of traffic, the culminating position of the railway in Persia; here it is 70 miles from the Caspian Sea coast, and 550 miles from Tiflis, the Russian military depot of the Caucasus. At Teheran, the railway will draw into its embrace the whole of the Persian east, west, and central traffic—Ispahan being just 300 miles due south—the traffic from the north-west district cities, viz., Choi, Tabriz, and Reschdt, a point on the Caspian being included. The railway thence passes eastward through Scharud, where it is 50 miles from Asterabad, and 70 miles from the nearest point of the River Attrek, goes on by Nischipur 4,000 feet above the sea level, Mesched 3,000 feet across the frontier of Afghanistan, and into Herat 2,650 feet, of which town Colonel Malleson lately gave to the Society of Arts a most vivid graphic and description, and which is 100 miles from the Persian frontier already crossed. At Herat it will no doubt meet "the Candahar railway" before alluded to, and now being constructed. It will pass by the towns Sebzar, Farrah, and Girischk, through Candahar, on to the frontier of the territory of the Khan of Kelat, not through the Bolan Pass, but by a more practicable one to the northwest, and somewhat parallel with it, lately discovered, and which possesses advantages political and constructive superior to those of its venerable rival route; it leaves Quetta 10 miles on its right, passes through the Pischin, towards Gwal, to Durgai, at the foot of the Chapar mountain, the village of Khost, the Hurnai valley, the Nari Pass, Sibi, Mithri, to Jacobabad, and Shikarpore, its termination. Here it will be placed in communication with the whole of the Hindostan railway system, through Lahore northwards, and *via* Bombay to the south, as soon as the gap between Kurrachee and Ahmedabad shall be completed.

Between, and including Swadia and Shikarpore, the railway will thus accommodate about 24 cities and towns of considerable importance, while it is practically safe from the most combative of the Arab tribes, their country lying at the west of the Euphrates; not that these nomads are anywhere to be greatly feared; they cannot be more difficult to manage than the Indians of the American continent, who were similarly somewhat dreaded at first by the promoters of the Pacific Railway of the United States, but who are now easily and effectually held in check.

The route for a railway to India, has now been traced from west to east, or from its termini on the Dardanelles and the Levant, to its junction with the Indian railway system on the Indus; and it is one which will bring with it all those advantages and facilities in which the iron road is so productive, to five great territories, viz., Asia Minor, Mesopotamia, Persia, Afghanistan, and Beloochistan, penetrating them in their most vital parts, and most active centers of national industry; in addition to which, England and the most important dependency of Great Britain—India—are connected by a magnificent artery of communication. But this is not all; the benefits of this railway will not be strained, and exclusively scattered, for the advantage of the countries named. Europe *en bloc* will feel its invigorating and refreshing influences, and to the races of Asia shall be brought that contact with civilization which is their birthright, when for the first time in the history of the world two continents shall become united by clasps of steel; let us endeavor that they may be forged and welded by England. It is certain, it is inevitable, that this, or some similar line of railway, will shortly be added to the category of accomplished facts.

We may, to some extent, arrive at an idea as to what may be the results of its opening, from the results which have followed the opening of the Suez Canal.

The course of trade has rapidly accommodated itself to the new waterway; France and Italy have now got each its line of steamers to India, making frequent voyages; Russia has got its lines of vessels trading from Odessa as far as China, which have almost wholly appropriated the tea trade between those countries, while, as for England, the number of her new ship companies going eastward is legion, and all this has occurred in much less than the ten years that have elapsed since the occasion of the marriage at Port Said of the Mediterranean and the Red Seas, while the Canal brings in a revenue sufficient to pay a handsome dividend on the capital invested. With such facts before us, we may most reasonably expect a profitable traffic from the railway, which will bring London and Bombay within seven days of each other, the cost of traveling by which, assuming the whole distance to be 4,800 miles, and rating the charge for passengers, first-class, at 3d. per mile, to include the expense of food *en route*, will be £60; second class, at 2d. per mile, £40—single fares. Much as we have learned to value railways, and fatigued as we are with the contemplation of the benefits they have conferred upon us, they still have surprises in reserve to delight and astonish us, and it is to the East that we must look for them.

The cost of the construction of a railway through these parts, as a single line of the first-class, with full station accommodation, and passing sidings, is generally computed to reach £10,000 per mile, the land being given *gratis* right through, equal to, from Constantinople to Shikarpore, a distance of 3,800 miles, a total of £28,000,000. The gross take from this capital expenditure, in order to pay five per cent., should be £2,800,000 per annum, or about £19 per mile per week. The present take of the Indian railways, double and single, is £27 per mile per week, and in the Island of Ceylon it is said to attain the large figures of £54 per mile per week. Whether or not £10,000 per mile will be sufficient to complete the railway, and equip it ready for working, cannot be said with certainty in the present condition of the question. Those persons who are acquainted with the character of the *terrain*, and who are familiar with the cost of the Indian and Russian single line railways, consider that the sum should be sufficient. As high speeds will be required, and heavy loads will have to be carried, the gauge should be that of the English and Continental and Turkish standards—of four feet eight and a half inches. Unfortunately, the Indian gauge is five feet six inches, so that a transfer of cargo will have to be made somewhere *en route*. If the gauge were to be that of the Indian railways, such transfer should take place at Scutari, on the left bank of the stream of the Dardanelles; but by adopting the ordinary English standard, the transfer would take place in Indian territory, which would be preferable. The Russian gauge is differentfrom both of those named, so that a break will also be necessary at junctions with the lines of that country.

Assuming the through distance from London to Shikarpore to be 4,800 miles, the time occupied on the journey, traveling night and day and continuously, would be, at 29 miles the hour, equal to seven days, which is as high a speed as it will be possible to travel the through distance for many years; and with the aid of modern appliances, such as Pullman cars, tatties, unexceptionable *cuisine*, &c., there is no reason why the journey should not be performed at all periods of the year, except, perhaps, two or three of the summer months, quite as comfortably as in going from New York to San Francisco, which is about a six days' ride. Mr. Allport, of the Midland Railway Company, has stated, in public, that he and his daughter having made the American trans-continental excursion, were not in the least fatigued, and had said to each other, on having arrived at San Francisco, that they could have at once started, without discomfort, upon the return journey, if they had felt it to be necessarry to do so.

The principal rival scheme to "the North Persian route," is that *via* the Euphrates Valley and the Mekran coast, which was so ably and so eloquently described in a paper read by Mr. W. P. Andrew, from this place, in February last. He would gladly accept the boon of "a railway to India" by installments, and so directed his attention on that occasion only to that portion of the route lying between the Levant and the head

of the Persian Gulf. Whatever may be the route finally adopted, Persia is the key of the position. Persia consists of but a ring of available country, its central points being a waste. It resembles a finger-ring, moreover, in so far as this, that its jewels are embedded in one segment only, that facing the North-West and North, and those jewels are the cities and towns of Choi, Tabreez, Reschdt, on the southern shore of the Caspian Sea, Hamadan, rather inland, Teheran, the capital, Scharud, and Mesched. There cannot, therefore, be a second opinion, from the point of view of traffic only, as to whether the northern or the southern portion of this ring is to be occupied by "a railway to India;" the inequality of distance between the two routes being inconsiderable. To judge from the minutes of evidence of the committee, the Mekran coast of Southern Persia is almost a *terra incognita*. One may observe scintallating through the fog that envelopes it, one town at 110 miles from the sea, that named Shiraz, worthy of the name, while Bushire, Bender-Abbas, Djask, Girischk, &c., seem to be insignificant places, and mere landmarks dotting the coast to guide the weary traveler as he rides over 1,400 miles of country—which is the distance from Mohammerah, at the head of the Persian Gulf, to Kurrachee, in Scinde. Again, a railway in these parts would be of that most objectionable class of line, "a coast railway." Fed only from one side, it taps only half the country, and one-half of that population, which is the legitimate allowance of a railway well laid out and well placed at first.

It is by this South Persian route, commonly known as the Mekran Coast, that the Euphrates Valley Railway of Mr. W. P. Andrew can alone be extended to India, that is to say, it will pass through 1,400 miles of a district perfectly destitute of traffic, and with only one town of importance in that distance, which is Shiraz. Is it likely, except under circumstances of the most urgent necessity, that the railway to India will ever take up such a hopelessly barren and uninviting country? This is really the weak place in the scheme, and, to all present appearances, that which will be fatal to its adoption.

The Euphrates Valley route commences at Iskanderoon, in the Bay of Issus. It crosses the Beilan range of mountains, 2,100 feet high, at a short distance from the seaboard, passes through Aleppo, along the right bank of the Euphrates, visits the sacred places, Kerbela and Nedjef, and has its terminus at the fine harbor of Grane or Kowait, at the head of the Persian Gulf. Its merits are, the entire absence of engineering difficulties—bar the Beilan range—and the fact that Grane is an unexceptionable harbor, protected, healthy, having good anchorage, good drinking water, and being easily accessible. But, it has its disadvantages; it taps only one great town and center of trade, Aleppo; the places, Kerbela and Nedjef, however, are not to be despised. Well, that gives just three towns of importance along a route of 900 miles. Again, it is only "a fragment of a railway to India," as described by Sir H. Rawlinson, and when the through route to India is to be made, only a fragment of this fragment will be available. A great point made in its favor by its advocates, is this, that a Euphrates Valley railway would be an alternative route to the maritime canal of Suez, and useful accordingly in the event of a stoppage of the latter by an enemy; that, however, ought not to be; and if it shall ever be attempted by Russia, she must first march across the alternative route, and if able to stop the canal, she can, *à fortiori*, stop the alternative. The breaking of bulk at each extremity of this railway of 900 miles in length, would moreover be an insurmountable obstacle in the way of its carrying a goods traffic, upon the carriage of which there would be a saving of time of three days at the most.

When considering the question of a railway to India, its supporters and its pioneers, it would be ungenerous to overlook the part that the indomitable Chesney performed in introducing it. Just 50 years ago he made his first notes as he traveled in the districts concerned, submitted them to the King, received a grant from the House of Commons of £20,000 for the purpose of making surveys, which grant was supplemented by £5,000 from the Indian Government, took his orders from the Duke of Wellington and Lord Ellenborough, and hav-

ing had two small steamers built by Laird, of Birkenhead, and being full of enthusiasm for the enterprise, and buoyed up by the patronage of the King, he sailed from Liverpool on the 10th of February, 1835, in the ship *George Canning*, carrying on board his little iron squadron, stowed in pieces, as well as the *personnel* of the expedition, destined for the navigation and *reconnaissance* and survey of the Euphrates. He is gone, but, I hope, not to be forgotten whenever the truly great enterprise of an improved—and a railway—communication with India is being discussed. Contemporaneous events are worthy of note, as we pass on with the subject. The Liverpool and Manchester Railway was opened in 1830; the charter of the East India Company was abrogated in 1833; and Richard Waghorn established "the overland route to India" in 1834. It was Waghorn's route that caused the collapse of Chesney's *via* the Euphrates Valley. I take the opportunity to pay a humble tribute of respect to the memory of a gallant, generous, and brave spirit, and a born explorer.

The question as to that point on the Levant from which the railway should start, has caused some difference of opinion. Swadia possesses many and probably superior merits to any of the others. It was the port selected by Chesney for his landing; it is the port of the town of Antioch, eleven miles inland, with 10,000 inhabitants; it is irreproachable in the matter of health; it possesses an excellent anchorage and holding ground; it is the only port on the Syrian seaboard from the north down to Beirut that is not backed and separated from the interior by a mountain barrier. Chesney thus describes it:—

"The bay is seven miles wide, and encircled by a mountain girdle of striking grandeur, varied here and there by spots of most attractive scenery. Southward, a wall of rock rises from the valley below the wooded sides and bold peak of Mount Cassius, from which the outlying range of Gebel el Akrab runs eastward, at an elevation of 5,318 feet. Parallel to this bold range is the valley of the Orontes, with the hills of Antioch, showing near its termination; more northward, still forming the opposite horn of the Bay of Antioch, is Gebel Musa, a wooded and picturesque mountain, with the caverns and excavations of Seleucia in its lower slope, which terminates this magnificent panorama. The little town of Swadia, though scarce a mile from our ship, is completely hidden in the dense mulberry plantations which surround it. The scene before us was magnificent; for grandeur, beauty and extent, it could scarcely be surpassed."

The River Orontes rises in the mountains of the Lebanon in about the latitude of Beirut, and flowing north and parallel with the Syrian coast for about 100 miles, it turns sharp to the west, and in a winding course forces its way through a defile in the Swadian amphitheatre, debouching into the sea at the centre of the bay. It is through this defile that it is proposed to carry the railway, upon a mean gradient of 1 in 234, and the gradients will be unexceptionable. The winding river will have to be crossed by bridges several times, and a sea wall must be run out to enclose a harbor, for which there is abundance of stone hard by. Nature has done much for this port, and art must perform her share in making it perfect. General Chesney says of this portion of the question, in his paper read before the British Association, 1857—

"Alexandretta does not promise to answer, on account of the mountains; ancient harbor of Seleucia also condemned, not sufficient depth; but on the south side of the bay of Antioch, a spot selected by Sir John MacNeil, admirably adapted for a safe and commodious harbor of refuge, can receive second-rate line-of-battle ships, and will be as good as the harbor of Kingstown. The spot is three miles south of the river Orontes, and six miles east of the old harbor of Seleucia. Harbor to be made by running out a breakwater on south side of a natural harbor; a perfectly safe and secure harbor for boats, with good holding ground. Stone of finest quality abounds close to where breakwater abuts on land; 1,000 feet of breakwater to be carried out at first instance, vessels of 18 feet draught of water may lie there during first 18 months. Harbor complete, shelter for 30 to 35 vessels; 20 to 40 feet deep; two chain bridges over Orontes necessary."

The other ports on the Syrian coast

are Ayas, Iskanderoon, El Ruad, Latakia, Tripoli, Beirut, Sidon, Tyre, El Arish and Acre. Mercyne also, a port on the Cilician coast of Asia Minor, each of these has got its friends. Iskanderoon, on the south shore of the Gulf of Issus, which is said to possess a good anchorage, is strongly advocated, but it is unhealthy, and is cut off from the interior by the Beilan range of hills of 2,100 feet high, which should be crossed by the railway by a mean gradient of 1 in 21 for 8½ miles from base to summit, and a maximum of 1 in 13 for one mile; also on the other side a mean of 1 in 18 for six miles, and a maximum of 1 in 13 for 2 miles. At the time that this suggestion was made, the Mont Cenis Fell Railway was in fashion, with its gradients of 1 in 12½, and the generally complicated mechanicism of its locomotives, but further experience of that system has not tended to raise it in the estimation of engineers, except in exceptional cases. To carry a heavy passenger and goods traffic over a mountain, where it may be carried on very easy gradients, is hardly likely to be adopted, even with the temptation of a good and cheap harbor to start with. Tripoli has for its spokesman Captain Lovett Cameron. This port is 140 geographical miles in a right line from the city of Aleppo, against 70 miles from Swadia to the same city, which would add 70 miles more than is necessary to the length of the railway. The principal attraction of this port in his eyes is its roadstead, and the facilities that exist for making a fine harbor and a port of magnitude, which will of course cost money. He states that, after leaving the plains that fringe the sea, there are hills around Homs to be crossed, a long viaduct to be built, and a great cutting to be excavated, so that Tripoli presents a rather formidable catalogue of difficulties to be overcome.

The strategical aspect of this great undertaking stands forth prominently, and the route *via* the Mekran coast is pronounced to be the most secure from attack from the north. No doubt it is so at the first blush, and 1,400 miles of it, viz., from Mohammerah to Kurrachee, lying close to the coast, the line could be easily protected by our ships; the most that can be said, however, is that the railway is only somewhat more safe here than on the North Persian route, and not by any means absolutely protected; for instance, at Mohammerah the railway would be only 250 miles from Ispahan and 380 miles from Teheran, cities that could be easily occupied by Russia in the case of a great war with England, in which India was to be the prize. If the railway be carried by North Persia, it becomes a frontier line from Teheran to Herat for 600 miles. As far as Persia is concerned, it would, in this position, be that class of strategic railway which all nations desire to construct as soon as they possess the means. Such a railway is that of the London, Brighton, and South Coast line of railway in England. Russia possesses a similar frontier line, *via* Wilna, Grodna, Warsaw, Rowno, Balta, to Odessa. Other European States are protected in the same way; the object is manifest; such railways afford the means for rapid movements and concentrations between the flanks of an army for either attack or defence. Looking at the north Persian route, from a Persian point of view, it is just the line that country requires for defence; when, in addition to this, it gives her a direct and safe approach to the railway system of India, *via* Herat, Candahar, and Shikarpore, as well as an east and west line connecting the great cities and towns of her own country, there can be hardly a doubt as to her looking to such a railway as an essential member of her network of the future. If it be possible to effect a fusion of the railway interests of England and Persia, so much the better for both. By means of such a combination, we may look forward with hope to the early construction of "a railway to India," without it, the prospect, it must be confessed, is dreary to contemplate. From the railway concession given to Baron Reuter, some few years ago, which was brought about through the intelligent intervention of the Grand Vizier, Mirza Hassein Khan, we may judge of the anxiety of the Persian Government to inaugurate a railway system. This concession, at which, in the words of Sir Henry Rawlinson, "Europe stood aghast," however, came to nothing. According to the same authority, first, the Grand Vizier miscalculated the serious character of the Russian opposition; secondly, England's indifference; and

thirdly, the determined opposition of his own countrymen. Russia showed intense chagrin, because of the negotiation with a rival, and because her trade would be hampered by British *employés* at the Custom-house on the frontier. The merchants of Moscow and Astrakan compound with the Russian officials on favorable terms for duties, and they were alarmed at the prospect of a rigid examination of Customs dues at ports of entry; for these and other reasons they made a resolute stand against the concession. Baron Reuter found it impossible to place the loan, or form a company, and the contract was annulled in 1873.

There is one more consideration which ought not to be omitted, when speaking of our communications with India. Russia has had surveys made of various routes suggested to join her network with that of India, notably with that of M. Lesseps; are we prepared to stand by and allow her to do that which it is our own duty and interest to accomplish? The Rev. James Long says, "a railway from Orenburg to India is popular in Russia, 2,270 miles long, Peshawur being the objective point; the Russian mind is full of it. Hochstetter prefers the Caucasian Russian Railway."

It was stated last week, in the *Standard* newspaper, that the engineers of Russian ways and communications had lately placed before the Emperor, for his approval of one of them, two designs for connecting the Caucasus and Persia by railway, first, from Tiflis *via* Tabreez to Teheran; and second, from the port of Baku, on the Caspian Sea, *via* Reschdt to Teheran.

The distances taken from Kiepert's map of Vorder-Asien, by compasses, shows for the territorial distribution of the mileage of this "railway to India" as follows:

Turkey	1,000	miles.
Persia	1,000	"
Afghanistan	600	"
India	150	"
	2,750	"
Levant fork	250	"
	3,000	"

Twelve months ago it used to be said that Afghanistan would be the chief obstructionist, but twelve months of a period of vast national tension and effort are sometimes productive of vast and unexpected changes, that confound the wisdom of the wise, and reverse the predictions of the prescient. Now, we have changed all that; we have, to all appearances, got the wedge of control and tranquility well into the fastness of these lawless mountaineers, and shall be able to make short work of their interference with a railway; and, indeed, from some quarters we learn that, having heard of the great success of our Indian railways, and the amenities they confer on Indians, they (the Afghans) will be only too happy to have their country tracked by railways, and, in short, they look upon the fact that we have already made 140 miles of the Candahar railway, and that we mean to extend it; as a more powerful reason why they should cry "peccavi," than those of the visits which our projectiles have made them. We may, therefore, dismiss our fears as to Afghan difficulties in the matter of the 600 miles of "a railway to India" that fall to the lot of Afghanistan, and look forward with interest to the period not now far off, when the cry will be heard on the Indus Valley Railway at the Shikarpore station, "Train about to start for Quetta, Candahar, Farrah, and the North."

The kingdom of Persia will carry and care for 1,000 miles of our proposed line. Persia may be held to be the key of the enterprise. Here at once will be our greatest difficulty and our best successes, but our difficulty will not be with the people of the country. Our difficulties will be of a different sort, for it is here we shall first have to deal with Russia. From Persia herself, her Shah, her potentates, and her people, we have nothing but support and approval to anticipate. The country is ripe for the introduction of railways, and, without doubt, will welcome the proposal that they should aid us with all their strength in the construction of a moderately devised design to give their network of the future a start; which must not, however, be of that heroic type which Baron Reuter and Mirza Hassein Khan projected for their acceptance. As to the feelings of Russia in the matter of the Persian instalment of "a railway to India," that is an affair of diplomacy, and it ought to be possible to get it accomplished without paining

her susceptibilities. It is here that the strategical aspect of the design will require the greatest attention, and to this point of the route that the eye of the soldier will be most watchfully directed. No doubt, railways play an important part in warfare, but so they do in matters of commerce and trade, and do we not all look forward with expectation to the period when the only works they shall be called on to do shall be the works of peace. Russia is notably commercial in her tastes and desires, if she is also propagandistic and military, and it is notably from her commercial classes that the call now comes for a railway from Orenburg, or Tiflis, as may be, to Central Asia. Let us strive accordingly that our future rivalries with Russia in that quarter shall be rather commercial than militant, and that the diplomats of both countries may endeavor to solve the difficulties that will arise where dominant interests clash, and that they may crown the edifice by a treaty in which the rights of both nations shall be respected. Possibly, a determination on the part of Persia to connect her great commercial towns and cities by a trunk railway, running from West and East, may yet decide for us the strategy of the case by its entire effacement.

Turkey, and her quota of 1,000 miles, remains to be considered. She has long ago proclaimed her intention not only not to oppose a "railway to India," but to facilitate its construction by all the means in her power. So far, then, as enlisting the approval of the various nationalities through which the route will pass, things may be said to be fairly on the square. There is left the important factor of the approval of the enterprise by the national will at home. England shows signs of arousing, in the presence of the responsibilities that belong to and attach themselves to her. She demeans herself as if she had arrived at the conclusion that a policy of isolation does not pay for a country and a people who are to be found located in every degree of longtitude on the face of the earth, land or water. She has had a run of bad times, coincident with a period of restless languor, such as is not natural to her sturdy and practical mind. She had previously passed through a time of extraordinary, physical, and mental activity, in consequence of the invention of the railway. Other astonishing novelties followed in its wake, the gold discoveries, the telegraph, and the Suez Canal, which latter gave her shipowners and merchants as great a surprise and shock as they have probably ever experienced. New patterns of ships became essential, steam vessels alone were available in the canal, new mercantile principles and practice had to be adopted, smaller stocks of goods than before its opening sufficed for the exploitation of the trade to the East, in consequence of the shorter voyages made. Thus, practically, a considerable addition was made to supplies in hand, and glutted markets were the result, with all the troubles that follow them. But the good ship, though struck by a succession of squalls, has righted and refitted, and prepares for travel through new channels and seas. England is omnipresent in the world, how can she possibly confine her sympathies to the shires and boroughs of these narrow islands? Has she not become aware of this truth, and is she not now bracing herself to face it? as face it she must, or retire from the arena in favor of those who are more worthy of the world's confidence, if such there be. I trust it shall not be so, and that it will be found that the profusion of wealth which she holds has not yet emasculated her sons, as some philosophers have predicted it will inevitably do.

Two hundred and forty millions of natives of India, a gifted and most interesting people in many ways, await our fiat for the opening up of this route. That country has produced great statesmen and legislators, valiant warriors as well as eminent engineers, and architects of the highest capacity and artistic feeling, for where can be found on earth a building to surpass that beautiful and classic pile of marble the Taj-Mehal, and what country has produced a more able and successful ruler than Aurungzebe. I am convinced that there is now a necessity for this railway. I believe in its success. I am confident it will become a source of good fellowship, as it will be a new bond of union between us and them, and it is obvious that it will bring untold guerdons and gifts to lay at the feet of those outsiders who are the denizens of the two most populous of the continents of the globe, that is to say, of Europe and of Asia.

IRON AS MATERIAL FOR ARCHITECTURAL CONSTRUCTION.

By JAMES A. PICTON, F. S. A.

From "The Architect."

It would be fruitless to follow the various modern applications of iron which now extend into every department of industry. Machinery every year more and more supersedes manual labor, and machinery is identified with the use of iron. Whether for good or for evil, this is inevitable. It is the law of development, which no individual effort can prevent or retard. The inquiry remains, what is to be its influence in the future? That it will contribute materially to aid man's power over the material elements of Nature is certain. The moral results lie beyond the province of this paper; but it may be permitted to cast a forward glance at the probable influence of iron in one department, that of architectural construction and design. To what extent can iron be advantageously employed by the architect, and how far will it affect the æsthetic character of his work? All true design arises out of construction. Every style which has attained any eminence owes its effect to the adoption of its essential parts as sources of beauty, rather than to any attempt to conceal them. The use of iron, whether in construction or design, is a new source of power and effect put into the hands of the architect for good or for evil. The adoption of a new material should lead to new canons for its suitable employment, or rather to new applications of the eternal principles of truth and beauty.

Mr. Ruskin, who may justly be called the Corypheus of architectural critics, has some pertinent remarks on the use of iron in architecture. He speaks as follows:—

"Perhaps the most fruitful source of those corruptions which we have to guard against in recent times is one which, nevertheless, comes in a 'questionable shape,' and of which it is not easy to determine the proper laws and limits—I mean the use of iron. The definition of the art of architecture given in the first chapter is independent of its materials; nevertheless, that art having been, up to the beginning of the present century, practised for the most part in clay, stone, or wood, it has resulted that the sense of proportion and the laws of structure have been based, the one altogether, the other in great part, on the necessities consequent on the employment of those materials; and that the entire or principal employment of metallic framework would, therefore, be generally felt as a departure from the first principles of the art. Abstractedly, there appears no reason why iron should not be used as well as wood; and the time is probably near when a new system of architectural laws will be developed, adapted entirely to metallic construction."

This was written in 1849, before the era of great Exhibitions, Crystal Palaces, enormous railway-station roofs, and previous to the great improvements in the manufacture which have so much facilitated the employment of iron. At the present day it is scarcely probable that he would have written as follows:—

"Architecture being in its perfection the earliest, as in its elements it is necessarily the first, of arts, will always precede in any barbarous nation the possession of the science necessary either for the obtaining or the management of iron. Its first existence and its earliest laws must therefore depend upon the use of materials on the surface of the earth—clay, wood, or stone; and as I think it cannot but be generally felt that one of the chief dignities of architecture is its historical use; and since the latter is partly dependent on consistency of style, it will be felt right to retain as far as may be, even in periods of more advanced science, the materials and principles of earlier ages."

Again,—

The fact is that every idea respecting size, proportion, decoration, or construction, on which we are at present in the habit of acting or judging, depends on

the presupposition of such materials, and so . . . it may perhaps be permitted to me to assume that true architecture does not admit iron as a constructive material, and that such works as the cast iron central spire of Rouen Cathedral, or the iron roofs and pillars of our railway stations and of some of our churches, are not architecture at all."

There is more to the same effect, the rule laid down being "that metals may be used as a cement, but not as a support."

"But the moment that iron in the least degree takes the place of stone, and acts by its resistance by crushing and bears superincumbent weight, or if it acts by its own weight as a counterpoise; and so supersedes the use of pinnacles or buttresses in resisting a lateral trust; or if, in the form of a rod or girder, it is used to do what wooden beams would have done as well, that instant the building ceases, so far as such applications of metal extend, to be true architecture."

I have made these copious extracts from a writer whose power and influence we all admit, since nowhere else do we find the objections against iron as an æsthetical element, so clearly and lucidly stated. I would, however, with all modesty, suggest that much may be advanced on the other side. The principal use of metals, including iron, we are here told, is a *cement* for connecting stones together. Every practical builder knows that for this purpose iron is about the worst material that could be employed, its operation being to disintegrate and separate by its oxydation and expansion, and to destroy rather than support.

The unfortunate cast-iron spire of Rouen cathedral I give up as deserving the severest reprobation of the critic, not because of its being iron, but for its tastelessness and incongruity; but what about "the iron roofs and pillars of our railway stations," which we are told "are not architecture at all?" Writing thirty years ago, there was very little in such structures to attract admiration or attention, but look at them now. Westminster Hall, apart from its historical associations, in its wonderful roof exhibits a signal example of skill and beauty combined. This, says Mr. Ruskin, is true architecture. Turn then to the railway station at St. Pancras, with a noble roof four times the span of Westminster Hall, in the construction of which simplicity and skill have produced a result perfectly satisfactory to the eye on the score of sweep of its gigantic curves fills the mind with a sense of harmony and fitness which it is difficult to separate from a feeling of the beautiful. Why are we to deny to structures of this class the claim of being "true architecture?"

Surely the ultimate or radical principal of all true architecture is to use the materials within our reach, in such a manner as will bring out their capabilities most efficiently for strength and commodity, and superinduce upon their employment such decorative forms as the nature of the material may suggest. It is on this foundation that every style which has obtained a footing in the world has been based. What can appear more opposed to each other at first sight than the pure Greek of the age of Pericles, and the pure Gothic, say, of the thirteenth century? Yet diverse as they seem they are equally developments of the principle of truth and adaptation. The materials of both are stone, but the Greek stone being marble, led to a delicacy and refinement of detail of which the northern style was incapable. Given then the material to work with, and keeping in view that the main idea of the one was trabeation or horizontality, and that of the other pointed arcuation, the mind can follow the consistency and adaptation of all the parts, even to the minutest detail. Now can any one doubt for a moment that if iron had been equally available at the two periods in question, the genius which designed the Parthenon or that which soared aloft in the nave of Amiens or the choir of Le Mans would have been equally successful in the design of a metallic structure, especially looking at the beautiful bronze works of the Greeks, and at the rich fancy which characterizes the metal works of the mediæval artists. To prohibit such an attempt, or to limit the exercise of invention, would be "to put a yoke upon the necks" of our rising architects, "which neither our fathers nor we were able to bear." The mischief arises from the attempt "to put new wine into old bottles," to cramp and confine the use of the new material with-

in the lines of the old, with which it is altogether incongruous.

A curious illustration of this tendency may here be mentioned. During the revival of Gothic architecture, about the early portion of this century, the late Thomas Rickman, who did excellent service in explaining and popularizing the study, was employed to design a considerable number of churches in the revived style. Whether owing to the want of skilled masons or from motives of economy, a large portion of the details of these churches were executed in cast iron; tracery, mullions, labels, finials, crockets, even piers and arches. The effect, it need scarcely be said, was poor, thin, and incongruous, and the attempt was an utter failure. If iron is ever to take its place as an independent factor in architectural design, it must be by adopting a new point of departure, ignoring its conventional uses as a mere auxiliary to other materials, and treating it boldly on its own merits and capabilities. The Scylla and Charybdis of architectural art have hitherto been concealment and imitation; concealment of the real construction and imitating in one material the characteristic properties of another.

Let us turn to Mr. Ruskin again. He sets out with the plain principle:

"Know what you have to do and do it, . . . expressing the great principal of success in every direction of human effort; for failure is less frequently attributable to either insufficiency of means or impatience of labor, than to confused understanding of the thing actually to be done. Whatever is in architecture, fair, or beautiful, is imitated from natural forms; and what is not so derived, but depends for its dignity upon arrangement and government received from human mind, becomes the expression of the power of that mind, and receives a sublimity high in proportion to the power expressed. All buildings, therefore, show man either as gathering or governing, and the secrets of his success are his knowing what to gather and how to rule."

These observations are just and true. Let us now endeavor in a general way to apply them to the subject before us. What are the peculiar properties of iron, more especially wrought iron, as a material for building? I should sum them up briefly, as strength combined with lightness and plasticity. These qualities are admirably fitted for construction and decoration in some cases, and not so well adapted in others, and skill and taste are required for their just discrimination and application.

When the scheme for the first great Exhibition in 1851 was launched, designs and proposals of all sorts were broached as to the design and construction of a suitable building. They all fell flat, and were pronounced by the public voice to be cumbrous and unsuitable, being based on the conventional forms of brick or stone building. In a moment of inspiration Sir Joseph Paxton pointed out how the difficulty could be surmounted by a structure of iron and glass. It is easy to ridicule this as a mere gardener's idea of an enlarged greenhouse. When Columbus made the egg stand on its end by giving the shell a slight bruise, the bystanders exclaimed that "anybody could do that," but the same fertile imagination and readiness of expedient led to the discovery of the New World; and Paxton's happy thought has been further expanded and developed so as to furnish a principle of construction now universally adopted in all buildings for a similar purpose. Where a large area has to be covered for bringing together a numerous assembly for a temporary purpose—such, for instance, as the Kibble Palace at Glasgow—there is no material and no mode of construction so economical and effective as the combination of iron and glass. It is, in fact, a tent constructed with durable materials. Modern improvements in the manufacture of iron have rendered this easy which would formerly have been impossible.

But it may be said this is a development in one direction only. What about houses, public buildings, churches, street architecture? I am not preparing a book of designs, nor can I point to a visible embodiment of the tendencies I am pointing out, but in all these departments there is progress already attained and a reasonable prospect of further rapid advance. I have already alluded to the increased employment of wrought iron in the roofs and floors of private buildings, especially in France. Beyond

the merely constructive portion, its use is extending in dome lights, galleries, entrance-doorways, windows, and balconies. In public buildings and churches there has been a timidity in the use of iron for roofs in a manner to combine strength with beauty. The iron roof when adopted is usually concealed. If an ornamental or decorated open roof is designed, it is usually of timber, except vaulting is introduced. There seems no good reason for this neglect. The adoption of iron might in the first instance require more invention and thought, but the great advantage of security from fire should be a sufficient inducement for the change. In all roofs of great span, the facilities of iron have utterly discarded timber. Street architecture, especially of a commercial character, seems to afford a wide field for the application of iron in a decorative form, but the hand of skill combined with taste will be requisite to prevent its becoming an abortion. Nothing could be more odious or repulsive than long lines of glazed fronts with no relief but flimsy metal bars, looking like houses of cards ready to fall with a breath of wind or the slightest concussion. I have known structures of this kind, perfectly safe in reality, but the outward aspect so flimsy and insecure, that tenants were afraid to trust themselves within the precincts. The true principles are not far to seek. The main lines should not only be strong, but made to appear so, massive if you will, exhibiting weight as well as strength. Within these outlines there may be wide open spaces where the true artist can exercise his taste, and give play to his fancy in a material plastic enough to take any form, strong enough for protection and resistance, and light enough to irradiate the interior even in the murky atmosphere of a city. We are not without hints even from the olden time. In many of the frescoes on the walls of the Pompeian houses, or of the ruined halls on the Palatine, there is a style of architecture displayed which may be the mere fancy of the artist, but which, whilst preserving the leading forms of classical design, exhibits a lightness and grace which would easily serve for models for execution in metal. Many of the shafts of bronze candelabra display the same grace and elegance of form. Amongst the arabesques of Raphael in the Vatican there is a display much of the same character. There is ability enough amongst our modern race of architects, if this course were pursued, to strike out a new path for the progress and adaptation of metallic, and especially wrought iron construction, which would undoubtedly lead to advantages and results not hitherto anticipated. It would be invidious to mention specific cases, but instances might be pointed out in which proceeding somewhat on the lines here laid down, the result has been fairly satisfactory.

THE FUTURE OF CONSTRUCTION.

From "The Building News."

The lintel and the arch have played a by no means unimportant part in the history of architecture, and it may be worth the inquiry how they have been modified by recent constructive expedients, and to what extent they have influenced architectural style. By these terms, in an extended sense, we may designate not only the covering of openings in walls, but the covering of areas; not merely the mode of opening a doorway or window, but the roofing of buildings as well. Of course, the lintel is typical of all forms of trabeate construction that ever existed, from the trilithons and dolmens of prehistoric times, to the perfect structures of Greece; so the arch may be said to represent every form of construction, in which the principle of abutment exists, as when the stones are made to abut upon each other, instead of simply reposing upon the walls. The principle of the arch was known to the Egyptians, as we see by the huge abutting stones over the entrance to the Great Pyramid of Gizeh, and the pointed-shaped ceiling to the sepulchral chamber of the Third Pyramid, which simply consists of large

stones strutted against each other, and the underside slightly curved to a pointed form; but the arch system was the system *par excellence* of the Roman and Romanesque and Mediæval builders, and it is to these developed forms that we generally look for an illustration of its construction.

In short, it may be regarded as a fact that every style has been the outcome, more or less directly, of the lintel or the arch. If we go back to the original forms of arched buildings, we find even a modification of the lintel; the wall at Tiryns, near Mycenæ, and the Treasury of Atreus are rather instances of corbelling, or a succession of horizontal layers of stone covering the opening. They show certainly that the ancients had no clear idea of the real arch, as we now understand it. The above structures are specimens of horizontal arches, such as are met with among all Pelasgic races, in India, and in Central America, and it is an interesting matter for speculation whether or not this form of arch in Greece and in Asia Minor owed its origin to wooden construction, as it undoubtedly did in India and America. In Buddhistic structures, and in latter forms of Hindu architecture, the corbel, or bracket, and the three-stone arch are common features, and the last is a simple compromise of the arch and lintel, which led in time to the more perfect arch of many radiating voussoirs, the top crosspiece becoming the keystone. Important results naturally followed from the discernment of the mechanical principle of the arch; it led to the vigorous but restless architecture of Western Europe, the grand churches of Provence and Aquitania, and the finely-equilibriated structures of the Middle Ages. But the architect of the Renaissance used both forms indifferently, and it is from this condition all modern architecture has been developing. We must not omit to mention here the introduction of another system of of supreme importance in construction, combining both the elements of the lintel and the arch—we mean the truss. As all ancient architecture has arisen from the two former, to the latter we must look for any new outgrowth, and we consider it to be one intimately related with the future of iron. In the discussion upon iron at the Royal Institute the other night, there was, as we anticipated, a decided disavowal of the capabilities of iron among the leading architects. Mr. White and Mr. Street both disclaimed any sympathy with its use, and we may take their sentiment as that of the school of architects they represent. But, while they openly reject iron as a material, they would probably acknowledge its value in combination with other materials. It is significant that many of those gentlemen who have protested against it have employed it in their buildings. As a matter of fact, its use has been forced upon an unwilling profession. The question, however, of architectural style depends so much upon the means of spanning openings and covering buildings, that iron, as a material, will sink before the much more important question it opens, and, it seems to us, the future of architecture will depend largely upon the use architects make of the lintel, or the arch. When it is considered that concrete can be combined with iron in such a manner that each material may exercise its full capability of work; that beams, and floors, and roofs can be constructed so as to form homogeneous and monolithic structures, merely resting their weight upon the walls, it will at once be apprehended that these forms of construction we now regard with repugnance, because they have only been tentatively tried by the engineer in a rough-and-ready sort of way, are only awaiting the thought and refining grace of the architect to make them take their place in the evolution of architectural styles. It is even, moreover, a consideration of weight in determining the question we have put, that the revival of terra-cotta manufacture, especially in large blocks, has a tendency to lead us to the lintel rather than to the arch. The manufacture of iron beams and trussed girders, though chiefly interesting when viewed from the engineering point of view, has led to the recognition of the lintel element. It is at least clear that round and pointed arches do not lend themselves kindly to commercial or domestic buildings, except in a decorative sense, and no architect would consent to use either on a large scale, unless it were properly constructed, and provided with abutments. The smaller decorative arches are simply

lintels, being cut in stone, or cast in terra-cotta. Again, the truss is really nothing more than a constructed lintel; it can be shaped by art into the form of the arch, or into any other pleasing form, while it admits of the utmost economy of material. On the contrary, a constructed arch is always a source of trouble and danger, and modern architects can, consequently, use it only as a subordinate feature in their buildings. The most beautiful arcuated and domical styles, such as those of India, are constructed, as we have seen, upon quite another principle. The dome of the Tomb at Beejapore has been instanced by Mr. Ferguson as a wonderful instance of internal equipoised construction, totally unlike the system employed by the architects of Europe. The horse-shoe arches of Saracenic buildings are really self-balanced arches. Such thoughts as these lead us to the conclusion that the construction of the future will depend more upon the solution of the question we have been discussing than upon the employment of a new material only. It will be a matter of the combinative value of iron, for instance, and the settlement in our own minds of the problem we have hinted that will lead the way to the evolution of a national style, if ever one is possible.

THE THEORY OF MODERN AMERICAN SUSPENSION BRIDGES.

By S. C. Professor CELESTE CLERICETTI, of Milan.

From the Proceedings of the Institution of Civil Engineers.

1. It is well known that the engineers of the United States have found a practical solution of the problem of long-span bridges. It is also known that the solution consists of an improvement of the simple suspension system which prevailed in the first half of the present century, but which has lost credit in consequence of its insufficient rigidity.

The railway bridge constructed on the new principle in 1855 over the Niagara by Mr. Roebling, to whom the innovation is principally due, which measures 250 meters between the towers, and over which locomotives have been running for twenty-five years, is a sufficient proof of the stability of the system, even without mentioning the other five or six bridges, including the last and largest one over the East river, between New York and Brooklyn, having a span of nearly 500 meters between the supporting points.

The new system, besides its principal element, composed of steel or iron wire cables, includes:

1st. A certain number of straight rigid girders, of the ordinary construction, connected with the cables by a series of vertical rods.

2nd. A series of inclined ropes radiating from the saddles and supporting the girder at equi-distant points, leaving unsupported only about the middle third of the same.

Another source of rigidity in the system arises from the cables, which instead of being disposed in a vertical plane, are inclined inwards; and also from a series of horizontal ties, which increase the lateral stiffness and diminish the oscillations from high winds.

Neglecting the inclination of the cables and the horizontal ties, three different elementary structures compose the system just described. First a flexible structure, which is formed by the cable; secondly, an articulated system constituted by the sloping ropes, joined at their lower end by a horizontal tie; and thirdly, an elastic system, the girder.

In the American bridges under consideration it does not appear that the extremities of the sloping ropes are connected by a horizontal tie; they are generally fastened either to the top or to the lower boom of the girder. But it seems to the author that the completion of the articulated system by a horizontal tie situated along the neutral axis of the girder, where it would only be subject to longitudinal tension, would be preferable to the American custom, which has the

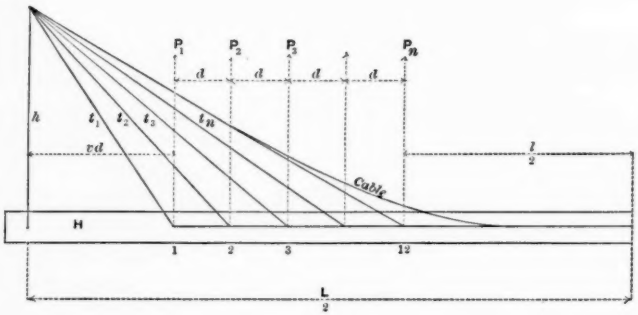
disadvantage of increasing the strains, either of tension or of compression along one of the flanges, producing a corresponding displacement of the neutral axis of the girder.

2. In order to ascertain the conditions of equilibrium of the compound system as defined, the author begins his research by taking into consideration the double structure constituted by a horizontal elastic girder, supported at both ends by the abutments, and at equidistant intervals by inclined ropes, radiating from two points situated on a level on the verticles above the supported ends. The sloping ropes leave part of the girder unsupported towards the middle, which part, in the bridges of this system already erected, varies from one-third to two-fifths of the whole span.

The combined structure is supposed at first to carry a uniform load, distributed over the whole length of the girder, the moment of inertia of which is taken to be constant between two joints, but to vary from one joint to the other.

By the ordinary process of analysis of elastic structures, three consecutive series of equations are deduced. The first series gives the bending moments M_k at any point between two consecutive joints; the second gives the corresponding inclination of the girder, and finally the equations of the third series give the verticle flexure.

By combining the equations of the first series with those of the third, a new series is obtained, which show the following property: the bending moments in any three consecutive joints are connected by the well known theorem of



Clapeyron of the three moments. Calling

M_{k-2}, M_{k-1}, M_k the bending moments of the girder in three consecutive joints;

s_{k-2}, I_{k-1}, I_k the moments of inertia of the girder in the same points;

$_{k-2}$, Is_{k-1}, s_k their vertical displacement from the original horizontal line, passing through the supports;

d = the constant distance of two joints, excluding the middle portion whose length is l;

q = the uniform load on the girder per meter; and finally

E' = the co-efficient of elasticity of the material of the same:

then the general expression arrived at, is

$$\frac{1}{d}\left\{M_{k-2}+4M_{k-1}+M_k\right\}=\frac{6E'}{d^2}$$

$$\left\{I_k s_k-2I_{k-1}s_{k-1}+I_{k-2}s_{k-2}\right\}=q\frac{d}{2}. \quad (1)$$

3. The principal condition which arises from the combination of the two structures analyzed is evidently this: the vertical displacement of the end of any radiating rope, produced by its elastic elongation, must be equal to the vertical flexure of the girder in the same joint.

Taking into consideration the articulated system, the vertical component of the elastic elongation of the k^{th} sloping rope is easily demonstrated to be, with sufficient approximation,

$$s_k=\frac{R}{Eh}l_k^2 \quad . \quad . \quad . \quad (2)$$

being

R=the maximum stress per square unity of rope section;

E=the coefficient of elasticity of the material of the same;

t_k=the normal length of the rope under consideration.

By introducing the above value in equation (1), and by putting

$$I_k = M_k \frac{H}{2R'} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

H =the constant depth of the girder;

R′=the maximum stress per square unit of section of the girder. By putting

$$\frac{R}{E} \cdot \frac{E'}{R'} = c \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and calling h the height of the points of suspension, above the neutral axis of the girder, equation (1) becomes:

$$M_{k-2}[3cHt^2_{k-2} - d^2h] - 2M_{k-1}[3cHt^2_{k-1} + 2d^2h] + M_k[3cHt^2_k - d^2h] = q\frac{d^4h}{2} \quad . \quad . \quad . \quad . \quad (5)$$

This equation contains as unknown quantities only M_{k-2}, M_{k-1}, M_k: therefore by making successively $k=1,2,3 \ldots n$, there will be deduced $(n-1)$ equations with $(n-1)$ unknown quantities, the moment M_n at the last joint near the middle being determined by the author by a different process.

Putting:

$$3cHt^2_{k-1} - d^2h = a_{k-1}$$
$$3cHt^2_{k-1} + 2d^2h = b_{k-1} \quad . \quad . \quad . \quad (6)$$

$q\frac{d^4h}{2} = C$, equation (5) becomes:

$$M_{k-2}a_{k-1} - 2M_{k-1}b_{k-1} + M_k a_k = C \quad . \quad . \quad . \quad (7)$$

The series of $(n-1)$ equations deduced from this are then solved, by the method of indeterminate coefficients, by introducing two series α and γ, of which the general expression is:

$$\alpha_k = 2\alpha_{k-1}\frac{b_{n-k}}{a_{n-k}} - \alpha_{k-2} \quad \gamma_k = 2\gamma_{k-1}\frac{b_k}{a_k} - \gamma_{k-2} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

being $\alpha_o = \gamma_o = 1$.

The value of M_{k-1} is then obtained, being

$$M_{k-1} = -\frac{1}{a_{k-1}a_{n-1}}\left\{C\left(\alpha_{n-k}\sum_{o}^{k-2}\gamma_x + \gamma_{k-2}\sum_{k+1}^{n}\alpha_{n-x}\right) + M_n a_n \gamma_{k-2}\right\} \quad . \quad . \quad . \quad (9)$$

The value of M_n deduced separately is

$$M_n = -q\frac{dh}{4}\frac{\frac{2d^2}{\gamma_{n-1}}\sum_{o}^{n-2}\gamma_x + d^2 + l^2}{a_n\left(1 - \frac{\gamma_{n-2}}{\gamma_{n-1}}\right) + 3hd(d+l)} \quad . \quad . \quad . \quad (9')$$

Introducing this value of M_n in equation (9) and making $k=1, 2, 3 \ldots (n-2)$, $(n-1)$ all the required moments will be obtained. These moments of flexure are all negative; it follows that, as on the contrary, the moment in the middle of the girder is positive, there are two points of contrary flexure in its curvature. These points are situated in the portion l of the girder, unsupported by the sloping ropes.

The vertical component P of the tension in any inclined rope is a linear function of the moments of flexure in three successive joints, the middle of which is the end of the rope; the general expression is:

$$P_{k-1} = qd + \frac{1}{d}[M_k - 2M_{k-1} + M_{k-2}] \ldots (10)$$

$$P_n = \frac{q}{2}[L - (2n-1)d] + \frac{1}{d}(M_{n-1} - M_n) . (11)$$

L being the total length of the girder.

But the portion of P_{k-1} and P_n which depends upon the moments, or the second term of each expression, being always comparatively small, either plus or minus, a sufficient approximation for practical use is attained by assuming $P_{k-1} = qd$=constant.

$$P_n = \frac{q}{2}[L - (2n-1)d] \ldots (12)$$

That is to say: the vertical component of the tension on any inclined rope, can be assumed equal to the weights applied to the girder, from the middle of the left, to the middle of the right bay.

When applying these formulæ and the preceding, (10) and (11), it must be remembered that k varies from 1 to n.

The knowledge of the vertical component allows the horizontal component or thrust to be easily deduced, and from any of them the resultant or the longitudinal tension on any inclined rope may be found.

4. In the numerical applications of the summarily recapitulated theory the value of c (4) is assumed by the author to be $\frac{3}{2}$

when both ropes and girders are of iron, on the consideration that for simple tensile stress, as that to which the ropes are exclusively subject, the maximum stress R can be taken at $\frac{3}{5}$ of the corresponding limit R′ of the girder. And even should the girder be of wood and the ropes of wire the fraction $\frac{R}{E}\cdot\frac{E'}{R'}$ can still be assumed $=\frac{3}{5}$, because the value of E′ for wood is about 100.000 kilogrammes per square centimeter, while E for iron is 1,800.000 kilogrammes, so that $\frac{E'}{E}=\frac{1}{18}$. Then, assuming as mean value R′=37 kilogrammes, and R=1,000 kilogrammes per square centimeter, it follows again that $C=\frac{1}{18}\cdot\frac{1000}{37}=\frac{3}{2}$ nearly.

The vertical deflection in the middle of the girder is given by the formula

$$s_m=-\frac{5}{384}9\cdot\frac{L^4}{E'I_m}+\frac{1}{E'I_m}\left\{\frac{dL^2}{8}\sum_1^n Px-\frac{1}{6}\sum_1^n Px^3\right\} \quad . \quad . \quad . \quad (13)$$

in which I_m is the moment of inertia of the girder in the middle, and

$$\sum_1^n Px = P_1+2P_2+3P_3+\ldots+nP_n$$

$$\sum_1^n Px^3 = P_1+2^3P_2+3^3P_3+\ldots+n^3P_n.$$

The author has applied the preceding theory to some American bridges, amongst them to the Niagara bridge of 1855. As regards the same, Mr. Malézieux states that the deflection of this bridge, when loaded through all its length by a heavy railway train, does not exceed 25 centimeters. The above formula gives

$$s_m=-479{,}749\frac{R'}{E'}.$$

The girder being constructed of wood, supposing the maximum stress in the upper and lower flanges to be R′=50 kilogrammes per square centimeter and E=100.000, as before stated, then

$s_m=-0.239$ meter, or 24 centimeters.

In order to explain how this result has been obtained, it is necessary to state that for want of knowledge of the real dimensions of the flanges, and hence of the value of I_m, the author has introduced in (13) for I_m its value as a function of R′ and M_m; hence the expression appears as a function of $\frac{R'}{E'}$.

The author has also deduced some approximate values, which are necessary for the further prosecution of the theory, and which are useful for practical applications. The approximate value of the moment of flexure in the middle of the girder is

$$M_m=+q\frac{l^2}{12} \quad . \quad . \quad . \quad . \quad (14)$$

l being, as already mentioned, the length of the middle portion of the girder, unsupported by the inclined ropes. The approximation given by this formula, compared with the exact one, which is

$$M_m=q\frac{L^2}{8}-d\sum_1^n Px \quad . \quad . \quad . \quad (15)$$

can be judged by the following results:

	Exact (15).	Formula (14).
1. Niagara bridge of 1855 $\frac{M_m}{q}=$	828,622	833,000
2. East River bridge $\frac{M_m}{q}=$	1,907,571	2,338,500
3. Bridge of 150 meters span $\frac{M_m}{q}=$	194,000	208,300
4. Bridge of 110 meters span $\frac{M_m}{q}=$	128,348	133,330

The approximate value of the moment at the end of the middle part of the girder is:

$$M_n=-\tfrac{1}{2}M_m=-q\frac{l^2}{24} \quad . \quad (16)$$

The approximate value of the deflection in the middle is:

$$s_m=-\frac{1}{64}q\frac{l^4}{E'I_m} \quad . \quad . \quad . \quad (17)$$

which, for the Niagara bridge gives, by the same process as before stated,

$$s_m=-538{,}829\frac{R'}{E'}$$

and for $\frac{R'}{E'}=\frac{50}{100.000}$ $s_m=-0.269$, instead of 0.24 meter.

Remembering that the moment of inertia has been assumed variable from one joint to another, this result can be usefully compared with the corresponding value of vertical deflection in a girder of the same material and length, equally loaded, under the assumption that the moment of inertia is variable. Assuming I to be subject to the conditions that the minimum stress R′ per square unit of cross section of flanges is constant, the author shows that the deflection in the middle would be proportional to $\frac{6}{384}$ instead of $\frac{5}{384}$, which is the value corresponding to a constant moment of inertia. That is—

$$I_m=-\frac{1}{64}q\frac{L^4}{E_m I_m}$$

which, compared with the last one shows that the deflection in the two cases would be as the rate $\left(\frac{l}{L}\right)^4$, so that the influence of the sloping ropes is clearly manifest.

Another result pointed out by the theory, and useful for practical applications, is that the distance of the first joint of the radiating ropes should be greater than the succeeding ones, in order to prevent the reaction on the abutment becoming negative; or, which is the consequence, to prevent the sloping ropes carrying all the weight of a girder, a condition which is realized in all the bridges of the system erected in America, in every one of them the first bay being longer than the others.

5. In the second part of the work, the principal object of which is the determination of the influence of moving loads, the point of departure is the general expression—

$$M_{k-1}l_{k+1}[a_{k-1}+h(l^2_{k-1}-l^2_k)] - M_k(l_{k-1}+l_k)b_k+M_{k+1}a_k b_k = l_k l_{k+1}h(C''_k l_k+C'_{k+1}l_{k+1}) \quad . . \quad (18)$$

in which the distances of the joints are supposed to be variable, being

$$l_1 \quad l_2 \quad . \quad . \quad . \quad l_k \quad . \quad . \quad . \quad . \quad l_n,$$

and the distribution of load also variable. In the same formula are

$C'_k=2M'_k+M'_{k+1}$ $C''_k=2M'_{k+1}+M'_k$,

M'_k and M'_{k+1} being the moments of flexure in the joints k and $(k+1)$ separated by the length l_k, if this portion l_k of the girder is fixed horizontally at both ends. The symbols thus adopted suppose the load to be distributed either on a portion or on the whole length of a bay, the case being excepted in which the load is reduced to a single weight applied at a joint. Calling z the length of the part of bay l_k loaded by p per meter on the left side, so that the remaining portion (l_k-z) is unloaded, the values of C′ and C″ are

$$C'=-\frac{pz^2}{4l_k^3}(2l_k-z)^2,$$

$$C''=-\frac{pz^2}{4l_k^3}(2l_k^2-z^2).$$

If, on the contrary, the load is applied to the right side, over the length (l_k-z) then C″ must be changed into C′ and *vice versa*, and z in (l_k-z) in the given values. If the load covers all the bay, then $z=l_k$, therefore,

$$C'=C''=-p\frac{l_k^2}{4}.$$

The general values of the series a and b are:

$$a_k=3cHt^2_k-l^2_k h \quad b_k=3cHt^2_k+2l_k l_{k+1}h \quad (19)$$

Equation (18) for $k=1, 2 \ . \ . \ n(n+1) \ . \ . \ . \ (2n-1), 2n$, gives $2n$ equations containing as unknown quantities the $2n$ moments at the joints. But, as they also contain in each value of a and b the quantity (4)—

$$c=\frac{E'}{R'}\cdot\frac{R}{E}=\mu\cdot\frac{R}{R'}$$

representing by μ a constant the question would appear insoluble, if the rate $\frac{R}{R'}$ varied from one joint to another, or in the same joint by changing the distribution of the load. However, calculation leads to the result, that P_k acquires its maximum positive value by the same distribution of load for which M_k is the maximum negative, a result in accordance with the ordinary theory of continuous girders, in which the maximum of the reaction on a pier and of the negative moment are due to the same distribution of load. From this and other considerations, it follows that the rate $\frac{R}{R'}$ is constant throughout the whole

length of the girder, whatever may be the distribution of the load.

Once ascertained that $\frac{R}{R'}$ is constant, the next step is to solve the equations deduced by (18), which is done by the process, already mentioned, of indeterminate coefficients, and with the assumption that the distance of the end of the girder to the first sloping cable is $\nu\ d$, d being the equal distance of the consecutive joints, except the middle part, whose length is l.

Owing to the symmetry of the system, the two series of indeterminate coefficients, necessary for the general case, are reduced to one. The expression of M_k for any distribution of load is:

$$M_k=-\frac{h}{a_k\delta_{2n}}\left\{\begin{array}{l}\delta_{2n-k}d^2\left\{(C''_1\nu+C'_2)\right.\\ \quad+\sum_{2}^{k-1}(C''_x+C'_{x+1})\delta_{x-1}\left.\right\}\\ \quad+\delta_{k-1}d^2\\ \qquad\left\{(C''_{2n}+C'_{2n+1}\nu)\right.\\ \quad+\sum_{k+1}^{n-1}(C''_x+C'_{x+1})\delta_{2n-x}\\ \quad+\sum_{n+2}^{2n-1}(C''_x+C'_{x+1})\delta_{2n-x}\left.\right\}\\ \quad+\delta_{k-1}l\\ \qquad\left[(C''_nd+C'_{n+1}l)\delta_n\right.\\ \quad+(C''_{n+1}l+C'_{n+2}d)\\ \qquad\left.\delta_{n+1}\right\}\end{array}\right. \quad (20)$$

The quantities belonging to each single bay are then separated in this expression in order to ascertain the influence of each. On examining the successive values of the series δ, it appears, first that their numerical value increases from δ_1 to δ_{2n}; and then, that while $\delta_1\ \delta_2\ \ldots\ \delta_{n-1}$ are always positive, $\delta_n\ \delta_{n+1}\ \ldots\ \delta_{2n}$ can either be positive or negative, their sign depending upon the quantity

$$a_{n+1}=3\ c\ H\ t'_n-l^2\ h\ .\ .\quad (21)$$

being positive or negative.

If this quantity is positive, then the numbers δ are also all positive. The consequences of this property are the following:

1st. If a_{n+1} is negative, (max $-$) M_k takes place by loading the $(n+1)$ bays at the left, and also the middle portion l, and consequently (max $+$) M_k corresponds to the complementary distribution of load.

2d. If a_{n+1} is null or positive, (max $-$) M_k takes place when the girder is entirely loaded; then (max $+$) $M_k=o$.

Consequently the quantity a_{n+1} may be termed the fulcrum of the question relating to the influence of the moving load on the systems analyzed.

Now the sign of a_{n+1} evidently depends on being (21):

$$3cHt'_n\gtreqless l'h\ .\ .\ .\ .\ .\quad (22)$$

that is, it depends on the value of the rate $\frac{H}{h}$ between the depth of the elastic girder and the height of the suspension towers. It appears then that a proper choice of the rate $\frac{H}{h}$ is necessary as having an important bearing on the greater or less flexibility of the system, the distribution of load corresponding to (max $-$) M_k, and hence the degree of rigidity of the two combined structures depending essentially on the said rate. The expression (21) being simple it appears easy to choose *à priori* a convenient depth of the girder in relation to the height of the towers.

It does not seem necessary that a_{n+1} should be positive. A sufficient degree of rigidity is acquired by making $a_{n+1}=o$, and even this limit should only be realized for railway bridges, while for ordinary road bridges it would be sufficient to assume for a_{n+1} a negative value not far from zero.

If $a_{n+1}=o$, then from (21)

$$\frac{H}{h}=\frac{1}{3c}\left(\frac{l}{t_n}\right)^2\ .\ .\ .\ .\quad (23)$$

l being comprised between $\frac{1}{3}$ and $\frac{2}{5}$ of the total span L.

Taking now into consideration the principal suspension bridges of the system, erected in America, it appears that in the Niagara bridge of 1855, which is undoubtedly the most rigid, and the only one constructed for railway use, the rate $\frac{H}{h}$ adopted by Mr. Roebling is nearly equal to the value deduced by making $a_{n+o}=o$, being $\frac{H}{h}=0.303$ meter instead of 0.363 meter.

In the other bridges the proportion is inferior to the one deduced from (33); hence their rigidity is proportionately less.

6. The necessity for the principal elements of the system being well proportioned to attain sufficient rigidity will also appear from the following considerations. As the lower ends of the radiating ropes are to be connected by a horizontal tie, in order to neutralize the thrust or horizontal component of the tension along the ropes, the equilibrium of the articulated system requires that the sum of the horizontal components should be null. But any irregular distribution of the moving load will produce a horizontal thrust on one side different from that on the other, which difference must necessarily be supported by the girder. Hence, if the girder is not rigid enough, the load on one side will depress that side, but will raise the other, an effect similar to that which takes place in an elastic arch partially loaded. The consequence is that the inclined ropes towards the unloaded side, not being able to resist thrust, will be deflected. If the difference between the movable load and the permanent one is small, the compression on the ropes of the unloaded side will be so trifling as to prevent their being deflected. But the moving load, as for instance on a railway bridge, may be considerable when compared to the permanent weight; hence the necessity of providing a bridge of sufficient rigidity.

By making $a_{n+1}=o$, the theory indicates that the amount of flexure M_k is negative for any distribution of the rolling load; consequently the stress on the inclined ropes is always tension. In this case the difference of intensity between the stresses of two equidistant ropes will always be small; the reaction of the girder necessary to equilibrate the consequent difference of horizontal thrust must also be small. In the Niagara bridge, for instance, in which the condition $a_{n+1}=o$ is nearly fulfilled, it would be impossible, whatever may be the position of the traveling train, for any inclined rope to be deflected.

On the other hand, in the suspension bridge over the Niagara Falls, erected in the year 1869, for the exclusive use of foot passengers, where the unsupported middle portion of the girder is the half of the whole span, 386 meters, the depth of 2 meters given to the girders would be insufficient if the bridge had to be crossed by vehicles.

To prevent the rise of one side of the truss, when loaded, over the other, the engineer of this bridge has wisely introduced a number of guy lines under the girders, connecting them at many points with the abutments.

To complete this part of the theory the author has taken into consideration a discontinuous load on a single bay of the girder, a research which is of practical importance only for the middle part l of the same. The value of a_{n+1} is also, under this point of view, the key of the solution. If it is negative the load must extend only to a certain part of l to produce in a given point the maximum moment; while if a_{n+1} is positive, the maximum moment is produced by the bay being all loaded.

7. In the first two parts of the theory, which have been summarily recapitulated, the object of the author has been to ascertain the conditions of equilibrium resulting from the combination of the articulated with the elastic system. There remains now to be examined the further combination of these two parts with the third and principal part formed by the suspension cable. The research, it is well to state, can only be approximate, as the question would otherwise be extremely complicated. The point in view being essentially the practical application of results, the author refers to the approximate formulæ (14) (16) (17) which seem to be sufficiently exact.

The curve of equilibrium of a cable of constant section supporting only its own weight is a catenary, while if the load is uniformly distributed over the chord it is a parabola. Therefore, if the two different loads are contemporary, the curvature of the cable must be a special one partaking of the two loads mentioned. But as the weight of the cable can only be a fraction of the entire load, it may be, as it is generally admitted, that the curve of equilibrium is a parabola.

Let the origin be taken in the left suspension point, and let x y be the horizontal and vertical co-ordinates of

any point of the cable. Let p be the load per meter of the horizontal chord, L the span, and h the depression of the vertex of the cable below the points of suspension. The rise h of the cable is taken as equal to the height of the towers above the neutral axis of the girder; it is a condition introduced to simplify the calculations; hence the vertex of the cable is tangential to the axis of the girder. The equation of the curve, before flexure, is—

$$y=\frac{4h}{L^2}x(L-x) \quad . \quad . \quad . \quad . \quad . \quad (24)$$

After the deformation produced by the loads, from which the weight of the cable must be deducted, as the flexure produced by the same takes place when the cable is put up, let h' and y' be the values of h and y; the equation or curvature will then be—

$$y'=\frac{4h'}{L^2}x(L-x) \quad . \quad . \quad (25)$$

Let $h'-h=s_c$ be the deflection of the cable in the middle, and $y'-y=s'_x$ the deflection in the point x, y, then, from (24), (25)

$$s'_x=\frac{4}{L^2}x(L-x)s_c \quad . \quad . \quad . \quad (26)$$

In order to find s'_x the ends of the cable are supposed fixed, under the consideration that the change of length of the external portions of cable or anchoring chains produced by the load must be compensated during construction by a proportional rise of the vertex, and because the deformations produced by a change in the initial temperature are not here considered. The approximate length L′ of the parabola whose chord is L, is—

$$L'=L+\frac{8h^2}{3L}-\frac{32}{5}\frac{h^4}{L^3}+\&c.,$$

or, with sufficient accuracy:

$$L'=L+\frac{8h^2}{3L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

As the length of the chord is invariable, and as $d(h)=s_c$, it follows that

$$d(L')=\frac{16}{3}\frac{h}{L},$$

hence:

$$s_c=\frac{3}{16}\frac{L}{h}d(L') \quad . \quad . \quad . \quad (28)$$

The cross section of the cable being constant, while the stress varies from one point to another, the consequence is that the specific stress cannot be constant. Let α be the angle between the tangent in the point x y with the horizon, and T the tension in the same point, being Q the constant horizontal thrust. Then—

$$T=\frac{Q}{\cos\alpha},\ Q=\frac{pL^2}{8h}\cos\alpha=\frac{1}{\sqrt{\left\{1+16\frac{h^2}{L^4}(L-2x)^2\right\}}} \quad . \quad . \quad . \quad (29)$$

Consequently

$$T=\frac{pL^2}{8h}\sqrt{\left\{1+16\frac{h^2}{L^4}(L-2x)^2\right\}} \quad . \quad . \quad . \quad (29')$$

If an element ds of the curve is subject to the elongation d^2s, then, from a well known formula,

$$d^2s=\frac{ds}{E_cF_c}\frac{Q}{\cos\alpha},$$

F_c being the section of cable, and E_c the coefficient of elasticity of its material, and

$$ds=\frac{dx}{\cos\alpha},$$

the total variation $d(L')$ of the cable's length will be:

$$d(L')=\frac{2Q}{E_cF_c}\int_0^{\frac{L}{2}}\frac{1}{\cos^2\alpha}dx,$$

substituting the value of $\overline{\cos^2}\ \alpha$, and integrating between the given limits,

$$d(L')=\frac{Q}{E_cF_c}\left\{L=\frac{16h^2}{3L}\right\},$$

when, from (27),

$$d(L')=Q\frac{2L'-L}{E_cF_c},$$

otherwise, by putting $\frac{Q}{F_c}=R_c$ it follows that

$$d(L')=\frac{R_c}{E_c}(2L'-L) \quad . \quad . \quad (30)$$

By introducing this value in (28)

$$s_c=\frac{3}{16}\frac{L}{h}\frac{R_c}{E_c}(2L'-L) \quad . \quad . \quad (31)$$

and finally, from this and (26) it follows that

$$s'_x=\frac{3}{4}\frac{R_c}{E_c}\frac{2L'-L}{h}x\frac{(L-x)}{L} \quad . \quad . \quad (32)$$

8. An approximate value of the vertical flexure of the girder in the middle of its length has already been given (17); still, in order to render more explicit the influence of the quantity a_{n+1} (21) on the flexibility of structure, the author proceeds as follows:

Considering the middle portion l of the girder, unsupported by the ropes, uniformly loaded by q per meter, being I_m the constant moment of inertia, the differential equation of the deformed axis is—

$$E_m I_m \frac{d^2y}{dx^2} = M_n + q\frac{l}{2}x - q\frac{x^2}{2} \quad . \quad . \quad . \quad (33)$$

which, as already stated, has two points of contrary flexure, determined by the condition

$$E_m I_m \frac{d^2y}{dx^2} = o.$$

Introducing for M_n the approximate value (16), and calling the distance between the points mentioned l_o, then

$$l_o = 2l\sqrt{\frac{1}{6}} = 0.816l.$$

Integrating (33), and deducing the constant, which is

$$C = -\frac{1}{24}ql^3 - M_n\frac{l}{2},$$

it follows that

$$E_m I_m \frac{dy}{dx} = M_n\left(x - \frac{l}{2}\right) + q\frac{l}{4}x^2 - q\frac{x^3}{6} - q\frac{l^3}{24}.$$

Integrating again, calling y_n the deflection of the origin ($x=o$) where the moment of inertia is I_n, the preceding becomes:

$$E_m(I_m y_m - I_n y_n) = M_n\left(\frac{x^2}{2} - l\frac{x}{2}\right) + q\frac{l}{12}x^2 - q\frac{x^4}{24} - q\frac{l^3}{24}x.$$

The deflection y_n is produced by the elongation of the nth sloping rope, and the corresponding value is given by (2) or

$$y_n = \frac{R_t}{E_t h}t_n^2,$$

where E_t and R_t are the coefficient of elasticity and the maximum specific stress convenient to the wire of the ropes.

By substituting this value in the above equation, and calling the deflection in the middle of the girder s_m, the value of s_m is:

$$E_m I_m s_m = -M_n\frac{l^2}{8} - \frac{5}{384}ql^4 + R_t I_n \frac{t_n^2 E_m}{h E_t}.$$

Calling R_n the maximum specific stress in the girder at the point where the moment is M_m, being H the constant depth of girder, then, from the general equation between the moment of resistance and the moment of rupture,

$$R_n = M_n\frac{H}{2I_n},$$

which, introduced in the preceding equation, together with the approximated value of M_n (16) becomes:

$$E_m I_m s_m = -\frac{3}{384}ql^4 - \frac{1}{48}ql^2\frac{H}{h}t_n^2\,\frac{R_t}{R_n}\,\frac{E_m}{E_t}.$$

Considering now that in absolute value, that is, not considering the sign of the moments, $M_n = \frac{1}{2}M_m$, and also that the moment of inertia is constant along the span l, being I_m, it follows that R_n will be $\frac{1}{2}R_m$. By substituting this value and remembering (4) that

$$\frac{E_m}{R_m}\cdot\frac{R_t}{E_t} = c \quad . \quad . \quad . \quad . \quad . \quad (34)$$

the preceding gives:

$$E_m I_m s_m = -\frac{1}{384}q\frac{l^2}{h}[3l^2h + 16cHt_n^2] \quad . \quad (35)$$

The quantity a_{n+1} must now be recalled (21); or $a_{n+1} = 3cHt_n^2 - l^2h$. Remembering that if this quantity is null or positive, (max−) M_k takes place when the girder is completely loaded; and that the girder possesses a sufficient degree of rigidity if a_{n+1} is null, or else a small negative value, then

$$H = \frac{l^2h}{3ct_n^2}k \quad . \quad . \quad . \quad . \quad . \quad (36)$$

or

$$a_{n+1} - l^2h(k-1),$$

being k a fraction not far from unity, and whose maximum is $k-1$. Putting the value (36) in (35)

$$s_m = -\frac{3}{384}q\frac{l^4}{E_m I_m}[1 + 1.78k \quad . \quad (37)$$

which, for $k=0.6$ nearly, gives the approximate value (17)

$$s_m = -\frac{1}{64}q\frac{l^4}{E_m I_m}.$$

Putting now in (36) the value

$$I_m = M_m \frac{H}{2R_m},$$

and for M_m the value (14) the deflection becomes:

$$s_m = -\frac{3}{16}\frac{l^2}{H}\frac{R_m}{E_m}[1+1.78k] \quad . \quad . \quad . \quad (38)$$

which can be given under another form, in order to show more clearly the influence of k. Putting the value of H (36), the last gives:

$$s_m = -\frac{9}{16}\frac{c}{k}t_n^2 \cdot \frac{R_m}{E_m} \cdot \left\{\frac{1}{k}+1.78\right\}\frac{1}{k} \quad . \quad (39)$$

which shows how s_m decreases by increasing k, that is to say, the rate between the real depth of the girder, and the depth which is deduced by making $a_{n+1}=o$.

9. The first condition which must be fulfilled, as arising from the combination of the cable with the girder, is the following: whatever may be the distribution and the intensity of the load, the deflection of the vertex of the cable must be equal to that of the middle of the girder. That is to say, $s_m=s_c$; or by (31) and (37):

$$\frac{R_c}{E_c}\frac{L}{h}(2L'-L) = \frac{R_m}{E_m}\frac{l^2}{H}[1+1.78k].$$

Putting

$$\frac{E_c}{R_c} \cdot \frac{R_m}{E_m} = a \quad . \quad . \quad . \quad . \quad . \quad (40)$$

the preceding equation gives

$$h = \frac{HL}{al^2}(2L'-L)\frac{1}{1+1.78k}.$$

For the practical use of this formula, the approximation given by assuming $L'=L$ is sufficient: therefore

$$h = \frac{H}{a}\left(\frac{L}{l}\right)^2 \frac{1}{1+1.78k} \quad . \quad . \quad . \quad (41)$$

10. A second condition to be fulfilled is that the depth of the girder H should not be less than the limit beyond which its own weight would produce the maximum allowable specific stress R_m in the booms, otherwise the girder would not contribute to the rigidity of the system, especially in its middle part, and as a static element it would be little more than a parapet. This condition is easily represented.

Let ω be the cross section of one of the flanges or booms of a girder in the middle of its length; then the volume of the two flanges together, for 1 meter in length will be 2ω, which will nearly be the complete volume of the portion of girder considered, because the shearing stress is null in the middle when the load is uniform, and always small under other conditions of load. Still, as it is necessary to complete the trellis, two diagonals at least and a vertical rod must be introduced to join the booms. Then it may be admitted that the volume of these parts in the middle and for the length mentioned is about $\frac{2}{5}$ of the volume of a flange; assuming the diagonals to be inclined at 45°, and calling π the specific weight of the material, the weight of 1 meter in length of the girder in the middle will be

$$2.40\,\pi\,\omega.$$

Recalling the approximate value (14) of M_m, then:

$$\omega = \frac{q}{12}\frac{l^2}{H}\frac{1}{R_m}.$$

Let q_o be the weight of a length of one meter of girder, in the middle of its length, then from the two last expressions

$$q_o = \frac{2.40}{12}\pi \cdot q \cdot \frac{l^2}{HR_m},$$

and by putting

$$\frac{q}{q_o} = n \quad . \quad . \quad . \quad . \quad . \quad (42)$$

and deducing H

$$H = 0.20\,\pi \cdot n\frac{l^2}{R_m} \quad . \quad . \quad . \quad . \quad (43)$$

the minimum value of which, for application, should be the corresponding $n=1$, in which case the girder will only support its own weight; any other load would increase the stress in the booms beyond the limit R_m.

11. A third condition requires that every part of the combined structure should be so proportioned as to determine in the whole a state of sufficient rigidity. This condition has already been treated, and found to be represented by (36)

$$H = \frac{l^2 h}{3ct_n^2}k,$$

the maximum of k being $k=1$, as already stated.

Equalizing the three values of H (36), (41), (43), it follows that

$$ha(1+1.78k)\left(\frac{l}{\mathrm{L}}\right)^2 = 0.20\,\pi\,.\,n\,\frac{l^2}{\mathrm{R}_m} = \frac{h}{3c}\left(\frac{l}{t_n}\right)^2 k.$$

The first and third of which give

$$t_n^2 = \frac{k}{3ca}\,\frac{\mathrm{L}^2}{(1+1.78k)} \quad . \quad . \quad . \quad (44)$$

The second and third

$$t_n^2 = \frac{k}{0.6c}\,\frac{h\mathrm{R}_m}{\pi n} \quad . \quad . \quad . \quad . \quad (45)$$

And from these two the following is deduced:

$$h = \frac{1}{5}\,\frac{\pi n}{a}\,\frac{\mathrm{L}^2}{\mathrm{R}_m}\,\frac{1}{1+1.78\,k} \quad . \quad . \quad . \quad (46)$$

The length of the longest inclined rope is given by

$$t_n^2 = \left(\frac{\mathrm{L}-l}{2}\right)^2 + h^2,$$

which, placed in (44) gives:

$$l = \mathrm{L} - 2\sqrt{\left\{\frac{\mathrm{L}^2 k}{3ca(1+1.78k)} - h^2\right\}} \quad . \quad . \quad (47)$$

If the cable and the sloping ropes are both constructed of the same material, and if $\mathrm{R}_t = \mathrm{R}_c$, that is to say, if the maximum specific stress per square unit of section is also taken to be equal in both, or else if $\frac{\mathrm{E}_c}{\mathrm{E}_c} = \frac{\mathrm{R}_c}{\mathrm{R}_t}$, then by (34) and (40) is obtained c $a=1$; hence

$$l = \mathrm{L} - 2\sqrt{\left\{\frac{\mathrm{L}^2 k}{3(1+1.78k)} - h^2\right\}} \quad . \quad . \quad (48)$$

And when the rate k is taken $=1$

$$l = \mathrm{L} - 2\sqrt{\left\{\frac{\mathrm{L}^2}{8.34} - h^2\right\}}$$

12. The expressions thus obtained contain the principal geometrical elements of the three combined structures, and the conditions which they must satisfy, in order that the whole may possess sufficient stability; therefore they enable convenient proportions to be assumed between the essential parts of the system.

Formula (46) gives

$$\mathrm{L} = 5a[1+1.78k]\,\frac{\mathrm{R}_m}{\pi}\left(\frac{h}{\mathrm{L}}\right)\frac{1}{n}$$

which enables the largest possible span to be deduced, or a practical limit of length consistent with the rigidity of the system, and with given limits of specific stresses in each structure.

In fact from the expression obtained, it appears that L increases by increasing k, and also that L is inversely proportional to n. Now the maximum of k is (36) $k=1$, in which case the moments of flexure of the girder are always of the same sign, and consequently the rope cannot be deflected; and the minimum value of n is also (42) $n=1$, in which case the weight of the girder will, by itself, produce the maximum allowed stress per square unit of the given material. Putting then $k=n=1$

$$\max \mathrm{L} = 13.90\,a\,\frac{\mathrm{R}_m}{\pi}\left(\frac{h}{\mathrm{L}}\right).$$

Suppose the case of a wrought iron girder, then $\pi=7800$ kilogrammes per cubic meter, and $\mathrm{R}_m=8{,}000{,}000$ per square meter of section, a limit of stress which should not be surpassed by flanges or booms of an elastic girder. Then follows

$$\max \mathrm{L} = 14256.40\,.\,a\,.\,\left(\frac{h}{\mathrm{L}}\right) \quad . \quad . \quad . \quad (49)$$

For extraordinary spans the cables must be made of steel wire, like those adopted for the East River bridge; the rate between the coefficients of elasticity of steel and iron may be assumed at $\frac{5}{4}$, that is to say

$$\frac{\mathrm{E}_c}{\mathrm{E}_m} = \frac{5}{4}.$$

Finally, the rate between the maximum specific stresses in the iron girder and the steel cable may be deduced by assuming the mean values corresponding to the limit of elasticity of both materials, or $\mathrm{R}_m=15$ and $\mathrm{R}_c=30$ kilogrammes per square millimeter. Then $\frac{\mathrm{R}_m}{\mathrm{R}_c}=0.50$; hence from (40)

$$a = \tfrac{5}{4}\,.\,\tfrac{1}{2} = 0.63.$$

Substituting this value in (49) it follows that:

$$\max \mathrm{L} = 8981.53\left(\frac{h}{\mathrm{L}}\right).$$

Taking $\frac{h}{\mathrm{L}}=\frac{1}{10}$, a rate which has not been surpassed for large spans by any

suspension bridge yet constructed, the result is:

$$\max L = 898.15 \text{ meters, or } 900 \text{ meters.}$$

As for the length of the middle unsupported part of girder, it follows from (48) that $l = 276.80$ meters.

The maximum limit of practical span thus obtained is interesting from a singular coincidence. Mr. Malézieux states that Mr. Roebling, the inventor of the combined system under analysis, in a report addressed to the Council of Administration of the East River Bridge Company, declares that the span of the new suspension bridges could be increased without danger to 900 meters.

13. In order to appreciate by comparison the influence which the combination of the three structures has in relation to the maximum span, the author proceeds to deduce a corresponding limit for an ordinary suspension bridge.

Let p be the load per meter of chord, excluding the weight of the cable, ω the cross section of the cable, and π the specific weight of a cubic meter of the material. The greatest tension in the cable will by (29′) be obtained. Putting $x = o$

$$T = (p + \omega\pi)\frac{L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}.$$

Calling R the specific stress per square unit of cross section, it follows that

$$R\omega = (p + \omega\pi)\frac{L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}},$$

from which

$$\omega = p\frac{L^2}{8h}\cdot\frac{\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}}{R - \frac{\pi L^2}{8h}\sqrt{\left\{1 + \frac{16h^2}{L^2}\right\}}}.$$

By putting $h = k'\,L$ and deducing L

$$L = \frac{8\omega R k'}{(p + \omega\pi)\sqrt{[1 + 16k'^2]}} \quad . \quad . \quad . \quad (50)$$

The required limit of span evidently corresponds to $p = o$; then

$$\max L = 8\frac{R}{\pi}\cdot\frac{k'}{\sqrt{1 + 16k'^2}},$$

which result is identical with that given by Navier.

Taking R = 20 kilogrammes per square millimeter, $\pi = 7800$ and $k' = \frac{1}{10}$, then

$$\max L = 2209 \text{ meters.}$$

The conclusion is, that the condition of rigidity necessary for the new suspension bridges reduces to less than half the greatest possible span, corresponding to the rate of $\frac{1}{10}$ between the rise and chord of the cable.

The comparison may also be made, by assuming in both cases the same value of h. Putting in the last expression $h = \frac{900}{10} = 90$ meters, which can be considered as a practical maximum, or $k' = \frac{90}{L}$, the result is

$$L = 1500 \text{ meters nearly.}$$

Consequently, at the limit of 900 meters the girder would only bear its own weight against a given limit of maximum specific stress, and all the remaining load would be sustained by the cable. Beyond this limit the bridge could not be called rigid, and the load which the cable would be able to bear, besides its own weight, progressively decreases, until at the limiting span of 1500 meters, together with the rise of 90 meters, the extra load would be null, and its own weight would induce in the steel cable a stress of 20 kilogrammes for each square millimeter of cross section.

Sidney Exhibition.—The admissions to the "Garden Palace" during the time it was opened exceeded the most sanguine expectations, being about 1,022,000, without including the closing day. The amount received for admissions and concessions was about £45,000. This sum, though not quite equal to the original estimate of £50,000, would probably defray the ordinary working expenses of the exhibition. The total attendance was regarded as unprecedented, considering the sparse population of this great colony, and the distance from the other Australian colonies and other parts of the world. The number of judges was 204, besides the 100 judges at the auxiliary shows of live stock, wool, &c., and shows illustrating the vegetable kingdom. There were 7,070 awards sent in by the judges, and their reports will be published in a volume.

THE STRUCTURE OF STEEL INGOTS.

By D. K. TCHERNOFF.

Translated from Revue Universelle de Mines.

I.

Among all the materials which satisfy the needs of industrial pursuits, iron in its various forms plays a predominant part.

When metallurgy could not afford the necessary means to produce steel of good quality, and in sufficient quantity, iron, either cast or wrought, satisfied the greater part of the wants of industry. The methods of manufacture of the two forms are essentially different. The difficulty of fusing pure iron, together with the want of proper means to melt it, necessitated a recourse to the complicated and expensive operations of puddling, piling, and the like, with a great expenditure of fuel and the employment of powerful mechanical contrivances. The relative ease of fusion of cast iron permits us to substitute for the difficult work on the metal the lighter labor on softer material, such as wood, clay or sand. That is, in order to obtain an object of the most capricious form in iron, it suffices to make a model of it in wood, clay, or other analogous material; to make its impress in fine sand, and then to pour in the melted metal, which in cooling will have the desired shape and size. Of mechanical labor there remains only the trimming of the edges and the dressing of the surface. The larger portion of castings require no other finishing, and this process, compared with the others, is so simple, that it is always followed, unless circumstances prevent.

When the method of preparing steel cheaply, and of any desired quality and quantity, became a regular industry, the casting of various forms in steel would appear to be a direct consequence of progress in the art of founding. Of the numerous experiments made on casting steel in sand or metal moulds, a few only were crowned with success; especially did they fail in the case of the low steels. The defects were chiefly blow-holes or cavities arising from shrinkage, and sometimes cracks which appeared at the surface. On the other hand, the composition of the steel would not permit easy working of the product obtained. From these causes steel-makers limit themselves to casting ingots of the simplest possible shape, and then resorting to mechanical processes to obtain the desired forms.

Although the obstacles to be overcome in casting steel in moulds are great, yet the pursuit of this end should not be relinquished, in view of the enormous advantages to be gained. Success in this direction depending before all upon exact knowledge of the obstacles to be overcome, we can regard with interest all knowledge of the defects which appear in steel castings.

For this purpose take the most simple form, that of the cylindrical ingot, of which Fig. 1 represents a section. Instead of a compact mass, we find that the ingot contains a great number of cavities. On the right hand side we observe, beginning at the surface, where the ingot was in contact with the mould, numerous blow holes penetrating more or less to the interior of the ingot, according to the conditions in which it flowed in the mould, and depending upon the quality of the steel and the character of the surface of the ingot, whether rough or not.

In the upper part of the ingot is a large cavity of irregular conical shape, extending down along the axis. This cavity, with friable sides, forms a funnel around which the metal is pierced with little cavities. This friable character extends along the axis much below the extremity of the funnel, and includes some tolerably large cavities. Away from the axis of the ingot this character gradually diminishes, and finally disappears, so that a certain thickness of metal between the friable part and the rough exterior is a compact mass.

Under certain circumstances, which we shall discuss further on, we find but few cavities near the outer surface of an ingot cast in a mould. Then the rough surface is replaced by a prismatic structure. (See the left side in Fig 1.)

Examining the neighborhood of the fracture, we find that the prismatic layer is composed of an assemblage of irregular prisms, perpendicular to the exterior surface. The cohesion of the prisms among themselves is not very great, so that the ingots exhibit a parallel lined structure, and break most readily along the surfaces of contact of these prisms; the fracture having a silvery but dull appearance.

The prismatic layer is succeeded by a granular layer, more or less developed, that is to say of an assemblage of grains irregularly polygonal in shape, with a dull silvery white surface, resembling that of the needle-shaped prisms described above. After this granular layer comes a thickness of compact metal having a brilliant fracture; then we pass to the zone in which the friability increases regularly to the axis of the ingot.

We will discuss each of the conditions mentioned above.

The most ordinary defect is the conical cavity, which proceeds from the contraction of the metal in passing from the liquid to the solid state. The form of this cavity is in correlation with the conditions of cooling. The cooling and hardening, consequent upon cooling at the surfaces, begins without doubt at the bottom. As the upper portions fill the spaces left by the contraction of the

Fig. 1.

lower ones, the form of the cone is easily explained. The appearance of the funnel-shaped cavity is so well known that it would be superfluous to describe it in detail.

The researches of many metallurgists have, for a long time, been directed to the cause of the bubbles which are found in the steel ingot. It cannot be said that investigations thus far have resulted in a general agreement as to the origin of gas in the liquid steel. Some claim it is simply a solution of gas held by the melted metal; others that the gas is the result of chemical reactions between the liquid metal and the material of the crucible lining that contains it; others again attribute the origin of the gas to the mutual reaction of the constituents of the metal and the oxygen of the furnace or the exterior air.

We will not stop to criticise these opinions, each of which is based on facts which cannot be entirely ignored. But it is necessary to add that the causes indicated may act in such way that the gases contained in it result from their combined or simultaneous action.

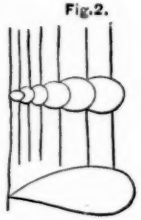
The one thing not disputed is, that the greater part of the gas disengaged is oxide of carbon, and that the time it is set free is the moment preceding the passage of the steel from the liquid to the solid state.

It is proper to conclude that the setting free of the gas from the liquid steel is governed by the same laws as the disengagement of gases, in general, from

liquids that hold them in solution. In steel, therefore, as in other liquids, it is most strongly manifested at the moment of shaking or pouring off the liquid. Thus the pouring of the charge from a Bessemer converter into the ladle, or from that into the ingot mould, is attended with a brisk ebullition produced by the escape of large volumes of gas.

The continued repetition of the oper-

Fig.2.

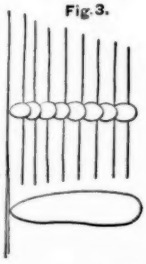


ation of pouring would result in the elimination of the gas, if we did not fear the metal would cool too much, and if we could at the same time provide against the oxidizing action of the air.

The moment the steel begins to cool in the mould, bubbles of gas form and attaching themselves to the sides of the mould harden.

The bubbles of gas forming in the mass of liquid would increase rapidly, being reinforced by the store of gas throughout the liquid; but as owing to

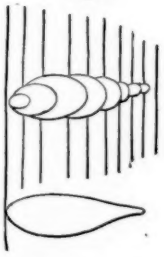
Fig.3.



the cooling influence of the sides of the mould, the layer of hardened metal is constantly increasing in thickness, the enlargement of the bubbles can only take place in a direction perpendicular to the sides of the mould. At the same time the form of the bubble will vary according to the relative velocity of its enlargement, and depending upon the increase in thickness of the layer of cooled metal. If the enlargement of the bubble is rapid, its diameter increases with its distance from the side of the mould, and it will take the form of a cone with a hemispherical base turned towards the center of the ingot (Fig. 2). When the bubble grows very rapidly the convex part sometimes detaches itself and floats. If the enlargement increases regularly with the cooling, the bubble takes the form of a cylinder with a hemisperical base (Fig 3). If, finally, the thickness of the hardened layer increases faster than the enlargement of the bubble, then the latter, although growing longer, contracts in diameter and terminates in a conical point (Fig. 4). Bubbles of this latter form are very rare.

As the mould becomes filled, the pressure of the liquid metal on the lower layers constantly increases, diminishing at the same time the escape of the gases,

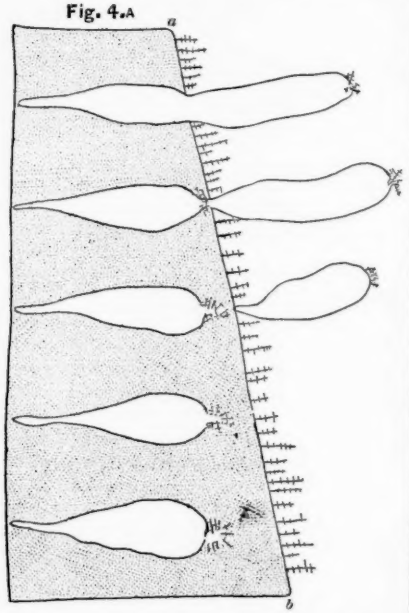
Fig.4.



and consequently arresting the growth of the bubbles in the lower portions of the ingot. The bubbles closing, the next layers of metal which solidify are compact and free from cavities, unless a new disengagement of gas is produced by an accidental fall of pressure. It may be added here that when the bubbles close, there is formed at the top a "funnel of contraction" lined with needle-shaped projections of which we will speak further on. It follows then, that if it were possible to prevent the formation of the first bubbles, which attach themselves to the first molecules of solidified steel, against the sides of the mould, the hardened crust would be free from spherical cavities, and the bubbles forming, not adhering to the sides would float to the surface, and the ingot would have a compact exterior. The phenomenon of adhesion of the molecules of

steel to the sides of the mould is analogous to the wetting of a solid by a liquid; the higher the steel is heated, the less will the sides of the mould be heated during the flow; on the other hand the more refractory the material of the lining of the mould, and the poorer its conducting power, the less will be the chance of its being wet by the liquid steel, and of the molecules adhering to it. We may conclude, then, that hot steel, not wetting the sides, would give in a metallic mould an ingot free from cavities on its outer surface; and that steel so hot as not to wet the sides of a

Fig. 4.A

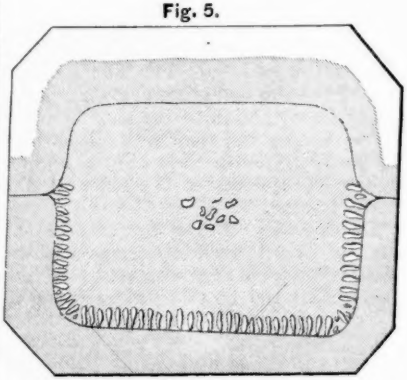


mould of refractory material will give a compact mass, while in a metallic mould the ingot would present bubbles.

An interesting experiment is performed by pouring steel of a medium temperature into a mould made partly of iron and the rest of sand. An ingot is obtained always porous on the metallic side, and altogether compact on the side next the sand lining. Figure 5 represents a section along the side of such an ingot, drawn to about one-eighth of the natural size.

The disengagement of the bubbles occurs at the instant of pouring or immediately after, while the gas can easily escape into the air, in part from the free and uncovered surface of the liquid, and partly in the form of bubbles that rise to the surface and break while the steel is yet liquid. When a crust begins to form the escape of gas is restrained. At the same time the absorbent power of the steel is lessened by reason of the lowering of the temperature; the gas accumulates under the crust, acquiring considerable elasticity, thereby tending to prevent the growth of the bubbles in the upper portions of the ingot. The bubbles previously formed are closed in by the hardened exterior layer, so that the escape of gas is nearly arrested. If the solidified layer is not very firm it will happen that the gas will force an

Fig. 5.



opening, and the steel and gas escaping together will form a frothy mass; the pressure being at the same time lowered, a new disengagement of gas occurs, accompanied by the formation of a second series of bubbles, mostly in the upper part of the ingot.

The contracted spaces at the summits of the first rank of bubbles serve as points of attachment for the second series.

This circumstance explains the well-defined limit between the zones of bubbles shown in Fig. 4.A, where the line *ab* indicates the limit between the liquid and solid metal at the moment of the fall of pressure, that is to say, at the moment the outer crust is ruptured.

Independently of the circumstances

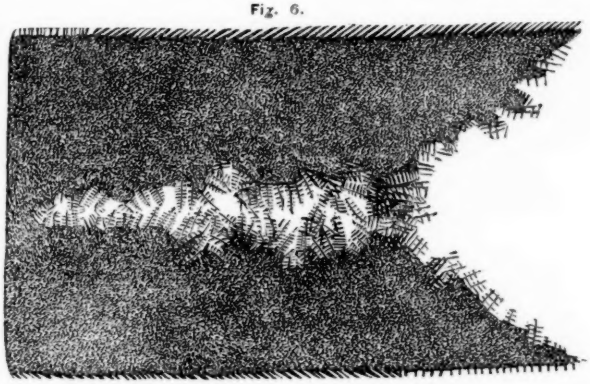
which we have analyzed, a disengagement of gas takes place under the solid crust, and ceases only with the moment of the solidifying of the last molecules at the center of the ingot. The cause of this disengagement of gas lies in the constant diminution of elasticity of the gas accumulated under the hardened crust, partly by reason of the cooling, and partly owing to the enlargement of the funnel of contraction. It is easy to comprehend how, as a result of the above conditions, the interior of a steel ingot should contain an enormous number of rounded cavities.

The interior surface of these bubbles is of a pure silver white tint, but as the exterior bubbles commence nearly at the surface of the ingot, and as their cavities are separated from the atmosphere by a very thin wall only, it happens that the oxygen of the air penetrates this wall during the solidification of the ingot, so that these inner surfaces are more or less oxidized according to the greater or less facility of communication with the outer air. The sides of the funnel of contraction are for the most part oxidized by reason of the rupture of the outer crust before the hardening is quite complete.

We will now consider how the solidification of the ingot proceeds from the outside towards the center.

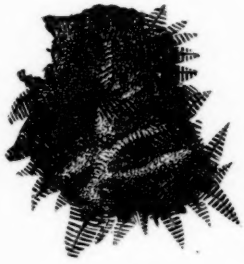
In observing the sides of a cavity of contraction, it is seen that they are covered with groups of entangled needle-

Fig. 6.



shaped crystals. An aggregation of such crystals in the funnel of contraction forms a porous looking mass in which

Fig. 7.



may be seen here and there cavities of considerable size. Figure 6 represents the lower part of such a funnel, and Fig. 7 a group of crystals taken from the friable sides of the central contraction of an ingot of 27 tons weight (having a diameter of $1^{m}230$, at a depth equal to one-fourth of the height of the ingot). The group is represented four times the natural size.

In observing these groups separately under the microscope, we notice that they have developed in directions following the axis of an octahedron, and that one of these axes, which is longer than either of the others, corresponds to the greater length of the crystal, so that each group forms a sort of skeleton crystal. Besides these axes of the first order, we find as we proceed from the summit of the crystal, axes of the second and third orders; at first only partly formed, and then more and more developed, until they form a kind of lattice

frame work following the lines of the octahedron.

Such a crystal is represented in Fig. 8. The dimensions of steel crystals, such as I have in my collection or have elsewhere seen, taken singly, rarely measure 5 millimeters in length. Generally they do not exceed 3 millimeters in length, and 1 to 1½ in thickness. It is difficult to state their minimum size, as I have seen well-developed crystals that required a magnifying power of 100 to 150 to make their shape visible.

Generally, the crystals in growing do not develop in parallel directions, but cross at different angles, as we see in Fig. 7; but occasionally they group into a hemihedral form, as shown in Fig. 9, which represents a crystal magnified about 70 times, taken from a cavity of

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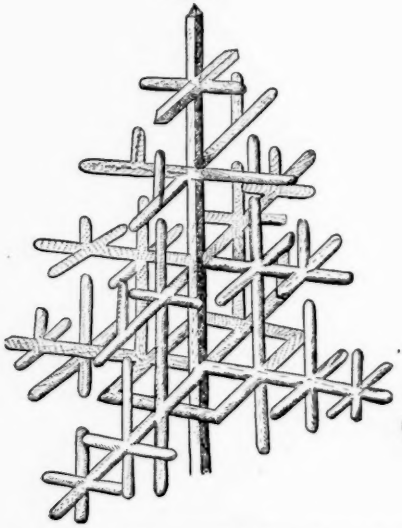


Fig. 9.

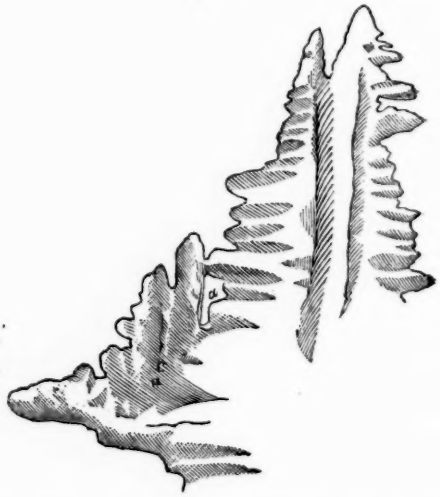


Fig. 10.

contraction in an ingot of 250 kilograms. Fig. 11 represents the outline of a crystal of the group shown in Fig. 7, magnified about 25 times.

As the sides of all the cavities, and the porous part which surrounds the central cavity, are formed of crystals more or less developed, we are justified in concluding that the solidification of the steel does not consist in the constant thickening of parallel layers, but by a continuous formation of crystals, commencing with the cooling at the exterior and extending to the center of the ingot. The principal axes of growth should be normal to the sides of the mould, as in Fig. 17. The radial structure of the outer layer of the ingot also demonstrates this fact when the steel is poured into a metallic mould so hot that but few, if any, exterior bubbles, are formed. (See Fig. 19.)

If the diameter of the ingot does not exceed 2 or 3 inches, the radiations extend to the center of the ingot (Fig. 12), and if it be of square section, the diagonals become well marked by the meeting of the lines of crystals, which are developed at right angles to the sides. The planes of these diagonals are "planes of weakness," and are well

marked in chilled iron castings (Fig. 13). It is necessary to add that in the cavities of foundry pig iron we find crystals which strongly resemble those we have been describing. It is therefore probable that the solidification of steel and of cast iron follow the same law. Fig. 14 represents a crystal from a cavity in whitish pig iron, magnified 70 times.

Numerous observations upon the

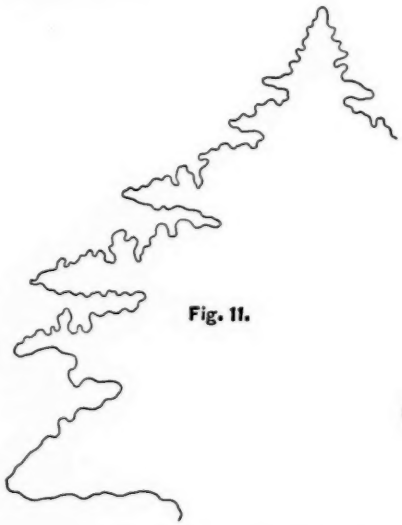


Fig. 11.

Fig. 14.

structure of the walls of cavities show that the higher the steel, that is the more carbon it contains, the better are the crystals developed.

In mild steels containing less than 0.20 per cent. of carbon we find the crystals with difficulty, and they are always of very small dimensions. There exists probably a direct relation between the capacity of the crystal to develop

Fig. 12.

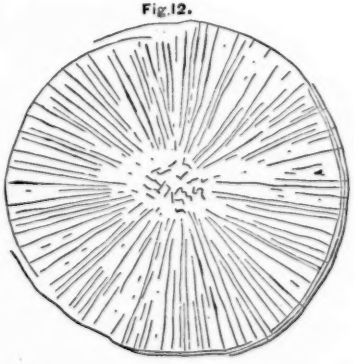
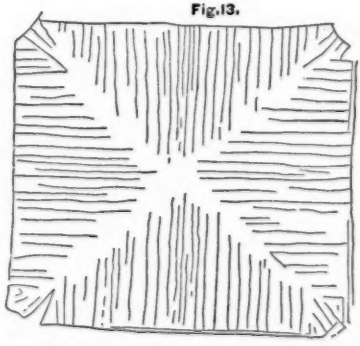


Fig. 13.



and the property of the metal, which permits it to pass rapidly from the liquid to the solid state without passing through a pasty condition, which interferes with the rapid and regular crystalline growth. It is noticed in cast iron that the white varieties which cool rapidly acquire a radiated structure, which indicates a rapid formation of crystals; while in the gray kinds, in-

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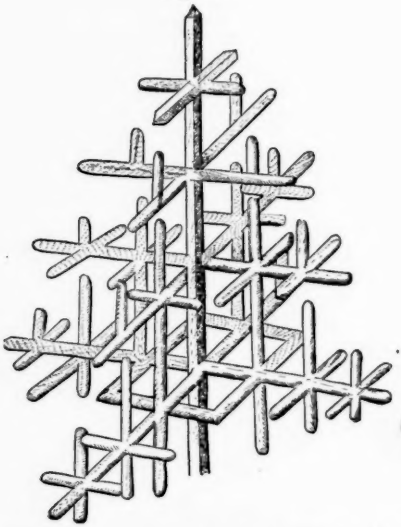
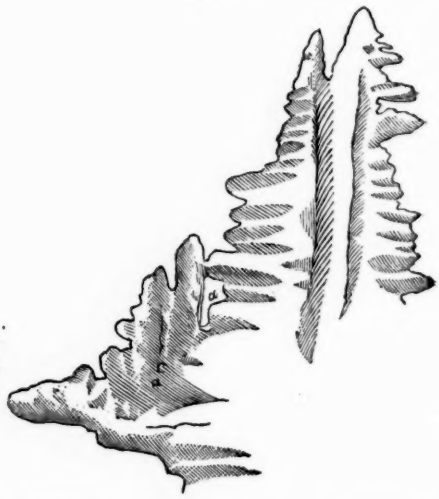


Fig. 9.



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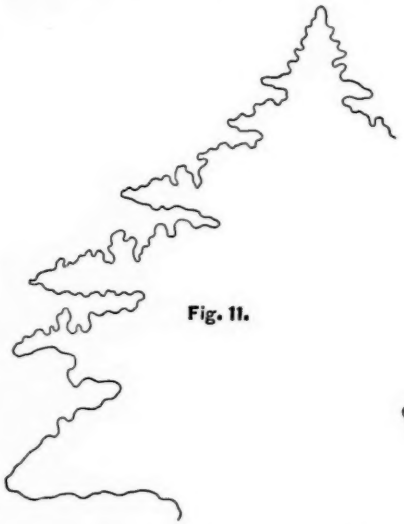

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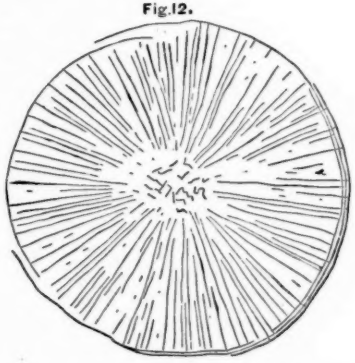
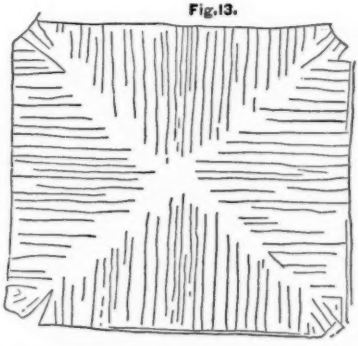


Fig. 13.



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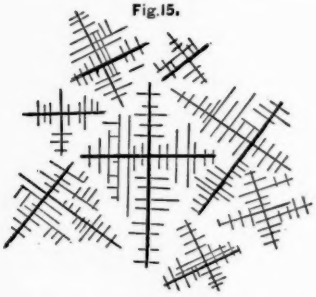
which the disengagement of carbon prevents the regular progress of crystallization, and which, in solidifying, pass through a pasty condition, exhibit a granular condition. The metal in crystallizing, while releasing the graphite, contains very little carbon chemically combined, although it probably retains the other constituents of cast iron.

In regard to the entangling of the crystals which form groups in the cavities of contraction, and in general in the central portions of the ingot, it is necessary to remember that the solidification of the steel in the central portions of the ingot is caused by the slow transmission of heat through the sides of the ingot which are yet red hot, although hardened. It therefore happens that crystallization begins simultaneously and grows from a great number of centers and proceeds in many directions. Furthermore, the central part of the ingot while solidifying, is in constant

Fig.15.



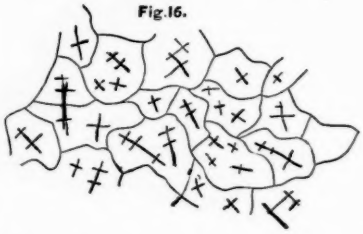
motion by reason of the sinking of the mass; this movement, although slow, is nevertheless quite sufficient to disturb the regularity of the growth of the crystals.

The chemical composition of these crystals, according to the analyses made at the laboratory at Obuchow, presents no regularity. They are always of the same composition, as the mass of ingot, whether it be high or low steel, so that there is no reason to suppose there is a definite combination of iron and carbon to form the crystal.

The crystals found in the hollows, formed in casting the ingot, have the same composition as the metal adjoining, but as the latter is harder than the mass of the ingot, it results that these crystals differ in being finer than those found in other parts, although having the same composition.

In describing the form of the crystals it was remarked that their growth was not perfectly regular; sometimes one

Fig.16.



side growing faster than the other; the axes of the second order developing faster than those of the first, they rob these latter of material—the axes meet and enclose between them a space filled with liquid steel.

In Fig. 9 the spaces $\overline{aa}$ are comprised between the axes of the first and second order; so that these spaces present themselves for separate crystals. The liquid metal of the enclosed spaces furnishes material for the growing crystals, but as the crystallization is attended by contraction, it happens that

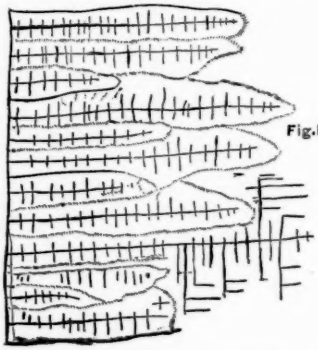


Fig.17.

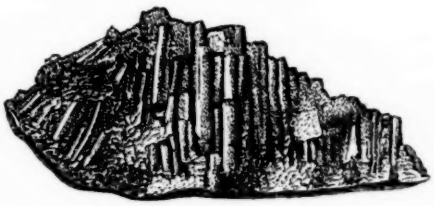
in each such closed space a little void is left which we will call the "local contraction cavity."

It is evident that the material for the regular development of the crystals is not readily supplied if the metal surrounding loses its mobility, a condition which is brought about during the hardening in the exterior portions of the ingot.

We may now see why the metal is found to be more and more porous as we approach the center of the ingot. The friability of the central portion is nothing more than the accumulation of local contraction cavities. On the other hand, the more compact the crystals, and the more rapid their growth, the more difficult does it become to supply material for their growth, even when the metal surrounding them is quite liquid. In circumstances similar to this must be the exterior portion of an ingot cast in a metallic mould, which rapidly absorbs the heat of the liquid metal; and this serves to explain the formation of the prismatic layer of the ingot, and the feeble cohesion of the prisms (Fig. 10). The local contraction spaces distribute themselves in such case between the planes of contact of the prismatic crystals, augmenting naturally near the

Fig. 18.

Fig. 19.



cooling surface. The prisms have generally an irregular cross section, first, because the lateral axes of neighboring crystals have between them no definite relation; secondly, the distances between the principal axes are not equal, therefore some of the crystals growing near each other produce hemihedral forms, while crystals further apart develop independently; thirdly, as was remarked above, the growth of single crystals is frequently not symmetrical with reference to the principal axes.

In illustration of the preceding remarks is presented the transverse section of crystals, as shown in Fig. 15. When the growth is complete the cross section of contiguous prisms is represented in Fig. 16, a condition which may be recognized in the fracture of steel ingots of prismatic structure. Finally, Fig. 17 exhibits the growth of crystals normal to the surface of the ingot.

UTILIZATION AND PROPERTIES OF BLAST FURNACE SLAG.

By CHARLES WOOD.

From the "Journal of the Society of Arts."

THE disposal of the enormous out-put of slag or scoria from blast furnaces has always been one of the serious difficulties of the iron trade. Taking an average of all the districts in England, for each ton of iron made, 25 cwt. of slag is produced, and from the official returns of last year of the iron smelted, no less than 8,000,000 tons of slag were produced. The space occupied by this mass, when loosely tipped, is something like 170,000,000 of cubic feet, or nearly twice the size of the Great Pyramid, whilst the bulk of the iron occupies only one-sixth of the same space.

There is, however, this great difference between iron and its refuse, that, whilst the former is diffused and finds its way into every corner of the world—from the hook at the end of the fisherman's line, or the hair-spring of a watch—from the magnificent steamship, or the abundant works upon the various railways, to the splendid roof of many of our public buildings, or the small but infinitely long rod of the telegraph wire—whilst

iron has been diffused through all these beautiful branches of the arts and sciences, its companion slag has been left behind at the smelting works, a hideous memorial defacing the landscape, absorbing something like a quarter of a million sterling annually in its disposal, and destroying forever hundreds of acres of valuable agricultural land, forming, as it were, a blot upon the face of the earth; and left as a landmark to show where this wonderful metal, iron, has been extracted, the development of which has contributed so much to bring the world to its present state of civilization.

That this state of things will entirely cease, the author does not, for one moment, think possible. So long as we produce such enormous quantities of iron, so long will these heaps go on accumulating. And there is little chance that these existing masses will ever be turned into a marketable product. At the same time, there can be little doubt that blast furnace slag possesses many valuable properties, which may, in certain localities, be converted into things useful to the arts and sciences, and—which is a most important point—at considerable profit.

There are other slags produced in many metallurgical operations—such as in the smelting of copper, lead, zinc, and tin ores—of which no use is made; but there are also slags, or cinders, produced in the manufacture of wrought iron, some of which are re-smelted, after which no great bulk of refuse is left. Nor is there, in the author's knowledge, any use whatever made of this residue.

Blast furnace slag, as it flows from the furnace when making foundry iron, is usually of a gray color, of much the same consistency as molten glass, a substance, in many points, it greatly resembles, particularly when the more siliceous ores are being smelted. It is very fluid, and has a temperature considerably above the melting point of cast iron; in proof of which, if a piece of cold cast iron be placed in a block, or wagon of fresh molten slag, it readily melts. At this high temperature, it contains a large quantity of gas, a considerable portion of which is thrown off or exuded as the slag cools down or becomes set. So much is this the case, that a large block or ball, technically so termed, will often burst, an hour or two after being run, from the accumulation of this gas in the inside. The bursting of these balls at the ironworks is of constant occurrence, and a source of danger, caused by the liquid slag and the outside shell dropping after the ball has burst. This is partially overcome by making the workmen knock a hole through the top crust before leaving the furnaces. Again, the least derangement in working of the furnace is quite sufficient to alter the nature of the slag, and often, within half an hour, will the slag be changed from grey to a perfect black. Such a color usually indicates imperfect smelting, and the slag will be found to contain a larger proportion of iron than it should do. Such, then, is the material with which blast furnace managers have to contend, and which forms their *bête noire*.

For many years the only known use for blast furnace slag was for road-making, and for this purpose it is still largely employed. In Northamptonshire, and in certain districts of Yorkshire, the whole of the slag produced is sold at a considerable profit. These, however, are local exceptions. Perhaps the largest user of slag is Mr. John Fowler, M.Inst.C.E., engineer for the Tees Conservancy Commissioners, whose works upon the breakwater at the Tees mouth deserve to rank as some of the most interesting in the kingdom. On these constructions Mr. Fowler consumes something like half a million of tons annually. A similar class of work is also being carried on at Barrow-in-Furness, from the slag produced at the hematite furnaces in that town; but, in consequence of the large amount of lime contained in this slag, much greater care has to be taken in its selection. The slag used at the Tees Breakwater is chiefly taken away upon bogies, in blocks weighing three and a half tons each. The slag is run into these blocks, upon the wagons, at the furnaces; a case or box being placed upon the bogie for this purpose. When the slag is sufficiently "set" this case is removed, and the wagon, with the block upon it, is taken a distance of about six miles to the breakwater. A large quantity is also tipped upon a platform on the river side, in such a position that the tide

completely covers it; it is then wheeled into hopper barges, belonging to and for the use of the River Tees Commissioners.

In consequence of the Tees Breakwater (known as the South Gare Breakwater) being now nearly completed, and the Tees Commissioners wishing to commence the breakwater on the opposite side of the river, called the "North Gare Breakwater," Mr. Fowler, in conjunction with the author, devised a plan for shipping the bogies with the hot balls into barges, and towing them down the river to a landing-stage constructed for discharging. Each barge is constructed to carry forty bogies, and will be about 220 tons burden. These barges will bring back the empty bogies on the return journey.

The loading of these barges at all states of the tide has naturally occupied a considerable amount of attention, and the machinery for shipment, designed by Messrs. Appleby Bros., of Southwark, and called a "Titan," has been recommended by Mr. Fowler, and generally adopted. Cantilevers, from a frame traveling on rails on the quay, overhang sufficiently to reach the outside of the slag barge, and a kind of overhead traveler runs backward and forward on these cantilevers, a distance of about 35 feet. The slag bogies are lifted and lowered by two steam-winches on the traveler, the centers of which correspond with the two lines of the rails upon the quay and upon the barge. A square shaft, running the whole length of the Titan, transmits all motions to the winches for lifting and traveling. Each winch has two drums for flat steel-wire rope, and these ropes are connected together by cross-beams, with slings for taking hold of each end of the bogies, the object being to pevent them from twisting when being lifted or lowered, and to ensure their coming directly upon the lines respectively on shore and in the barge.

The Titan is fitted with two lines of rails, one for full and the other for empty bogies. As already indicated, these lines correspond with those on the barge.

The mode of working is as follows:—When a barge-load of empty bogies are brought alongside, the bogies on the first transverse line are landed, and the barge is warped forward until the line which has been cleared comes opposite to the line for the loaded bogies; the traveling winch then picks up a loaded bogie, traverses out with it, deposits it in the barge, at the same time picks up an emptie bogie from the barge, then returns to the wharf, deposits it on the line for empties, and so on at each operation; so that the traveler takes out a loaded bogie, deposits it on the barge, and brings back an empty bogie each journey. The speeds of working are estimated to be equal to loading and discharging at the rate of 40 bogies per hour.

The engine, boiler, coal bunk, feed water tank, and counterweight box are fixed at the inshore end, and a platform on the traveler is provided for the driver, so that he stands directly above his work, and can clearly see each operation. One lever gives the motion of lifting and lowering, and another lever those for traveling in either direction. The whole of the work is performed by two men on the Titan, a stoker and traveler man, two men being required below to attend to the slings.

The next stage in slag utilization is the endeavor which has at various times been made of running the liquid slag, as it flows in a stream from the furnace, into moulds; or, in other words, making slag castings. Such an idea, at first sight, would seem natural enough. Here, it may be said, is a material flowing to waste, in a liquid state, capable of being run into moulds, and of taking impressions almost equal to that of cast-iron. The castings also, when successfully made, are exceedingly durable, and even beautiful to look at. So alluring has been the idea of casting, that, during the last fifty years, the Patent office has recorded, almost annually, the attempts of some inventor impressed with the notion that he could treat this treacherous fluid successfully, or, in some way or other, make it useful in the arts. To attempt to describe these various schemes, or to give even an outline of them, would occupy far too much time, but the author thinks that the following remarks will give a general idea of the difficulties he has had to meet.

The high temperature at which the slag leaves the furnace has been before noticed—namely, about 3,000° Fahr.—but, when it is brought into contact with anything cold, in the shape of a mould,

it readily parts with its heat, and, in so doing, suddenly contracts. The surface contracting becomes filled with fine cracks, or flaws; so much is this the case that, if allowed to become entirely consolidated in the moulds, these cracks will be found to penetrate completely through the casting, and, upon exposure to the air, the casting falls to pieces. This is the more vexing, as, when slag is run into a large mass—say into a pit of sand eight or ten feet deep, and containing from 30 to 40 tons—there is such an enormous amount of heat accumulated that it becomes self-annealing, the outside of the mass is kept at a high temperature, and, if allowed to remain until cool, not a flaw will be found, and the slag becomes so exceedingly tough and hard that it may be quarried in the same way as granite or Whinstone, and used for street paving.

There is, however, one exception to the numerous failures in slag casting, it is known as Woodward's patent, and although there is absolutely nothing new in the process, still, through the perseverence of Mr. Dobbs, the late manager and engineer for the furnaces of Messrs. T. Vaughan & Co., an amount of success has been arrived at sufficient to enable the company which works the process to pay a fair dividend. The success has been eminently a practical one, and appears to rest mainly upon two points—Firstly, in the quickness with which the castings are removed from the moulds and placed in the annealing ovens, where the temperature is constantly kept up nearly as high as the melting point of slag, the heat, after the ovens are full, being so gradually lowered that the outside of the casting cools at the same rate as the inside; the contraction is thus equalized throughout, strains upon the outside are avoided, and the fine surface cracks do not penetrate much below the skin. And secondly, upon the fact that only solid rectangular blocks, with a certain amount of bulk in them, are attempted.

On this wall is a diagram showing the apparatus and annealing ovens now in use at the works of the Tees Scoria Paving Block Company. The blocks are made by running the liquid slag into a series of open-topped moulds. The moulds are of cast iron, and are held by one end upon the periphery of a horizontal wheel or table. The wheel is suspended by tie-rods upon a central pillar. The moulds, when being filled up, are brought in succession under the slag-runner by the man in attendance, who watches until the mould is full. When the slag has become consolidated in the moulds a catch-hook is knocked up, the mould falls to pieces, and the brick drops to the ground. When they come out of these moulds, although consolidated, they are still in a sort of half-molten state, and are immediately removed into annealing ovens, which are always kept at a high temperature, so that the block receives no chill—the ovens are of small size, and, when full, are sealed up and allowed to cool down by themselves. There are about 70 moulds upon each machine, and the hotter these are kept the better; whilst, to prevent chilling of the molten slag, as it runs into the moulds, they receive a thick coating or washing of chalk or lime after each casting, the lime acting as a non-conductor as well as assisting the block more readily to drop out of the mould.

Thus it will be noticed that the casting is not allowed to remain in contact with anything which can extract its initial heat, so as to produce unequal cooling; and, as before stated, the whole success has been eminently a practical one, and reflects great credit upon those who have so patiently worked it out.

Large quantities of these bricks or paving blocks are used in the North of England for crossings, stables, yards, and streets; their durability, uniformity, and general appearance when well set is very pleasing. From a series of tests recently made, against a crushing strain, some of these blocks carried a weight equal to the hardest granite.

The next successful process for dealing with molten slag is that of Mr. Bashley Brittain's, who converts it, by a kind of compound process, into glass for bottle-making, and for many purposes where a pure white glass is not essential.

Sir Samuel Canning, Managing Director of Brittain's Glass Company, has kindly supplied the author with the following chief points of interest:

The slag is taken from the blast furnace in large ladles upon wheels, in quantities of about 500 lbs. In this state

it can be conveyed a considerable distance to the glass-works, where it is poured into a Siemens regenerative gas-furnace, known as the "continuous melting tank furnace." Through the kindness of Messrs. Howson and Wilson, of Middlesborough, the author is enabled to give a drawing of one of these furnaces, showing all the latest improvements. It has been designed by Mr. P. E. Eliott, late of Messrs. Chance Brothers, of Birmingham, the well-known glass-makers. It is arranged to work with gas made by a Wilson's gas producer, and is considered to be a great improvement upon the furnace employed at the slag glass-works at Finedon.

The material is fused and amalgamatal, in a melting tank. The fluid meted becoming fused, flows through a bridge, into a secondary chamber, called the gathering basin. The glass is withdrawn from this basin through a series of holes by the workmen, and fashioned into bottles, or other useful articles, in the usual way. By this arrangement, the work of charging and withdrawing the liquid glass is continuous, and proceeds uninterruptedly from Monday morning till Saturday night.

Messrs. Howson and Wilson assure the author that, with one of their gas producers, the consumption of coal per ton of slag glass should not exceed 10 to 12 cwts. With each charge of molten slag into the melting tank, alkalies and sand, and coloring or decolorizing material, are added in proportion, depending on the quality and color of, and the composition of, the glass required.

So far, the only slag operated upon is that produced from the Finedon furnaces in Northamptonshire, a very siliceous slag, the analysis of which is as follows:—

Silica	38.00
Alumina	14.87
Protoxide of iron	0.36
Protoxide of manganese	0.39
Lime	38.19
Magnesia	1.90
Titanic acid	1.00
Potash	1.58
Calcium. 1.55) as Calcium) Sulphur. 1.24) as Sulphide)	2.79
	99.03

To make bottle glass equal in quality and appearance to French champagne and claret glass, about 50 per cent. of slag may be used; for plate glass, the same proportion, or rather less of slag; but, for glass for heavier articles, a much larger per centage can be adopted. Bottles made from slag glass are stronger than those manufactured in the ordinary way from the usual materials, and will stand from 320 to 350 lbs. per square inch, half bottles (pints) from 420 to 450 lbs. per square inch. Slag glass, owing to its toughness, is especially suitable for manufacturing into tiles, cisterns, plates, pipes, slates, &c., for which glass is not now employed. The chief points of merit claimed for the process are the utilization of a waste product, the economizing the heat of the molten slag, and converting it, with additional materials, into good glass, quicker, and at less cost, than by the processes generally employed.

The author has now revised the various processes where the slag is used in its crude cold state, or where the molten slag is either run into castings, or dealt with as in Mr. Brittain's process, and will now proceed to describe the inventions and manufactures with which his name is associated.

In 1871, the waste land for the deposit of the slag at the Tees Iron Works being filled up, and the works of the Tees Conservancy having been temporarily brought to a stand-still, it became of serious moment to know what was to be done with the slag.

The cost of cooling the slag, and putting it on board barges for taking it out and tipping it into the sea, was so heavy, that it was suggested that the slag should be prepared in such a form that it could be tipped into the barges, in the same way as coal is done upon the Tyne and other places. To meet these requirements, several schemes were proposed and tried; amongst the first (and only successful one) is the horizontal rotary slag-cooling table, designed and patented by the author, and which, with little alteration, continues to work up to the present time.

The machine upon which the slag falls revolves very slowly, and is about 16 feet in diameter. The top of this table is formed by a series of slabs; these receiving or cooling plates, or slabs, are about two feet in width, each forming a segment of the circle. These plates are

kept cool by having a zig-zag wrought-iron pipe cast in them, through which water circulates, being fed from a center globe: the water, after passing through two plates, flows into the basin under the table. These water plates are bolted down in such a way as to be able freely to expand and contract. The liquid slag, as it flows from the usual runner, spreads itself upon the moving table into a broad band of slag, varying in thickness from half an inch to three quarters, depending upon the quantity and fluidity of the slag. From the point where the table receives the molten slag, a distance is traversed of about 10 or 12 feet, to allow the slag to consolidate; after which water from a jet is made to flow freely upon the surface of the hot slag until it reaches a set of scrapers, when, having become nearly cool, it is pushed off into iron wagons below.

When the slag reaches the scrapers, it has become somewhat brittle, and readily parts from the table and slides off in large flat pieces. When perfectly cold, it is tipped from the wagon, and falls into small-sized pieces, samples of which are shown. This material was christened by Mr. Fowler, the Tees Commissioners' Engineer, "slag shingle," by which name it is now commonly known.

The produce of this machine has found such ready sale that it has been kept going almost constantly ever since it started, and about 200,000 tons have been sold, chiefly for making concrete. In place of paying 6d. per ton to get rid of it, it has realized about 1s. 3d. per ton.

The large concrete blocks, each weighing about 230 tons, constructed by Mr. Fowler, for dropping into the sea, to form the head of the Tees breakwater, are chiefly composed of this material, and several heavy foundations for engines, drainage work, building, &c., in the district, have been executed with it.

The next great step in advance, and which has laid the foundation for the several processes hereinafter mentioned, was the reduction of the molten slag, as it flows from the furnace, into a soft spongy kind of sand, by a machine known as Wood's slag-sand machine. In principle it is the reverse of the slag-shingle machine, inasmuch as, instead of the wheel being horizontal, and the slag running upon a dry table, the slag flows into a wheel placed upon its edge, and falls into a bath of water, varying in depth from 18 to 24 inches. The wheel, or drum, is of wrought iron, and about 14 feet in diameter. It is fixed and carried on curved arms. The arms are curved, to allow, in the first place, the slag runner or spout, to enter the wheel; and, secondly, to make room for the sand-receiving spout on the opposite side at the top. The wheel makes about five revolutions per minute, and the water contained inside is partly carried up by the elevators and, in falling, causes a constant rush of water to the bottom. Perforated screens, or elevators, are arranged to screen the slag from the water, and lift it to the top of the machine, where it drops upon the sand-receiving spout, and thence slides in a constant stream into wooden wagons. The spout is also perforated, to allow any water which has been carried over with the sand to return again into the machine. The perforated buckets have another important function to perform, viz., that of agitating the water. The water, in rushing to the bottom, meeting these obstructions, rolls over in a violent manner, and into this agitated water the liquid slag flows just as it comes from the furnace. The united action of the agitated water and the formation of steam scatters, as it were, the molten slag in the water into the material called slag-sand, some of which is exhibited; as also a working model of the machine. The wear and tear of this machine is very light, there being no working parts coming in contact with the sand or the heat. The heat, being taken up by the water, is thrown off in the shape of steam, which comes away in large volumes. Grey slag takes up about 20 per cent. of its own weight in water. The total cost of this sand in railway trucks is about 6d. per ton. At the Tees Iron Works the author has three of these machines and two single machines generally at work.

On the Continent a kind of slag sand has been made—prior to the adoption of the process just mentioned—by running the slag into tanks full of water, and elevating the sand by chain buckets into wagons; but the apparatus is very imperfect, and will only work slag made

from forge iron, known as black slag. The application of slag-sand, in so cheap a form, to the useful arts naturally followed the production, and, after numerous experiments, extending over many months, it was decided to establish separate works in close proximity to the furnaces, where, under the author's own directions, various processes could be developed; and, in 1876, the first manufactory of the kind was started. Although in Georgemarienhutte, in Hanover, under the direction of Herr Luurnan, a process of brickmaking was started a few months previously.

The remarkable setting properties of slag in a state of subdivision has attracted the attention of scientific men for many years, and many schemes for producing artificial stone, cement, &c., have been tried; but, in consequence chiefly of the cost of disintegration, no results were obtained with commercial success.

Mr. John Gjers, of Middlesborough, about fifteen years since, produced a coarse kind of slag-sand, which, after grinding under edge-runners, was used extensively for some little time upon the pig beds; but it had to be abandoned, because it consolidated too much, causing violent explosions (technically termed "boils"), from the steam from the damp sand being unable to escape when the metal was run from the furnace in pigs.

Thus, it will be observed that, up to the time when the Cleveland Slag Works was started, there was not a single instance of slag utilization in this country—otherwise than for road-making, or for river work—commercially carried on. Before proceeding to describe the various manufactures produced at the Cleveland Slag Works, at Middlesborough, it is necessary to draw your attention to the chemical nature of the material operated upon. The following analysis gives a good general idea of the chief slags produced in the United Kingdom:

	Cleveland.	Hematite Bessemer.	Dowlais.	Dudley.
Lime	32.68	50.55	30.47	35.68
Silica	36.50	30.50	43.07	38.76
Alumina	22.95	15.00	14.85	14.48
Protoxide of iron	0.06	0.45	2.53	1.18
Protoxide of manganese	0.32	0.10	1.37	0.23
Magnesia	5.83	2.00	5.87	6.84
Potash	0.59	0.40	1.84	1.11
Soda	0.37	0.20	..	..
Sulphur	1.73	1.50	0.89	0.98
Phosphoric acid				
	100.90	100.70	100.89	99.26
Less oxygen of the lime combined with sulphur.	0.86	0.75	0.44	..
	100.04	99.95	100.45	..

A table of comparative analysis is given below, for easy reference. It will be noticed that three most

	Slag.				Portland Cement.	Slag Concrete Bricks.	Slag Cement.	Gypsum.	Puzzalanas.
	Hematite Bessemer.	Cleveland.	Dowlais.	Dudley.					
Lime	50.55	32.68	30.47	35.68	60.88	29.90	22.90	32.32	8.00
Silica	30.50	36.50	43.07	38.76	23.16	25.15	21.60	0.35	..
Alumina	15.00	22.95	14.85	14.48	7.68	21.80	19.85	..	..
Protoxide of Iron	0.45	0.06	2.53	1.18	..	1.44	4.00	..	..
Protoxide of Manganese	0.10	0.31	1.37	0.23	..	0.26	0.21	..	..
Peroxide of Iron	..	..	..	..	3.00	1.66	8 80	..	12 to 15
Magnesia	2.00	5.83	5.87	6.84	1 01	5.10	4.36	..	..
Potash	0.40	0.59	1.84	1.11	0.72	0.53	0.50	..	..
Soda	0.20	0.37	..	..	0.31	0.36	0.32	..	..
Sulphur	1.50	1.73	0.89	0.98	0.05	1.00	1.19	..	..
Sulphuric Acid	..	..	..	..	2.60	1.25	1.54	46.18	..
Phosphoric Acid	..	..	..	..	0.08	0.01	0.02	..	..
Carbonic Acid	..	..	..	..	..	2.60	3.00	..	..
Water (of crystalization)	..	..	..	..	0.77	9.50	12.00	21.00	..

important component parts of these slags are silica, alumina, and lime, forming, as they do, about 90 per cent. of the whole. The two latter of these, however, chiefly exist as silicates; if, to these caustic lime be added, the silicates are acted upon. Water of combination, or crystallization, is taken up; and, if the material be kept damp and exposed to the air, hardening or induration is carried on for months.

If caustic lime be added to slags poor in lime, so as to bring this element up to 55 or 60 per cent., it will be seen at once how closely it will resemble the analysis of Portland cement, the composition of which is as follows:—Lime, 60 per cent.: silica, 24 per cent.; alumina, 8 per cent.; oxide of iron, 4 per cent.

German Portland cement is sometimes made with as low as 55 per cent. of lime, whilst Roman cement has often only 50 per cent. of lime; but these will generally be found to contain oxides of iron in an increased proportion.

The remarkable hardening effect of oxides of iron in conjunction with lime, silica, and alumina, is well known, and is well exemplified in the Italian puzzolanas, where, in several of the best qualities, the lime is actually as low as eight per cent., whilst the oxides of iron run up to 12 or 15 per cent. The hardening effect of oxides of iron induced the author, prior to the development of the slag industries, to employ the dust from the ironstone clamps in place of sand, when making concrete for heavy foundations; and the setting properties and strength of this combination have upon examination been fully confirmed. Again, having to erect a row of columns for a large roof upon the bed of an old ironstone clamp, the floor of which had been accumulating for several years, it was found to be so extremely hard that the author simply levelled the bed down, and set the columns directly upon it. These, after many years, show not the slightest signs of settlement, although the ground underneath had been made up from ship's ballast.

It appears an absolute necessity for obtaining good results, that the ferruginous material should be calcined, or roasted, the effect of which is to drive off the carbonic acid and water; the reabsorption of the water, which unites in chemical combination with the material, afterwards assists in hardening.

These remarks would seem to be a digression from the question of slag utilization, but, as will be seen hereinafter, they bear directly upon the manufactures carried on at the Cleveland Slag Works.

The most important production, and the one which consumes by far the greatest quantity of slag, are concrete bricks, known in the market as slag-bricks. These bricks are made from the sand produced by the slag-sand machine before described. The sand is dropped from the railway wagons into hoppers, or depôts, at the works, from whence it is filled into large barrows, and is taken up a hoist to the top of the building, and tipped into a hopper, which supplies a measuring apparatus. Here it is mixed with a certain quantity of selenitic lime (General Scott's patent), with an addition of iron oxides; it then passes into the brick-press, hereinafter to be described. The bricks are taken off the presses by girls, placed upon spring-barrows carrying fifty bricks each, and removed to air-hardening sheds; here they remain a week or ten days, after which they are stacked in the air to further harden, and at the expiration of five or six weeks they are ready for the market. Specimens of these bricks are shown. We here have, then, the curious anomaly of bricks being made without burning, and of a wet season being favorable to the hardening process. The bricks thus produced are very tough; they do not split when a nail is driven into them, and are easily cut; they do not break in transit, and the frost has no effect upon them. According to a certificate received from Kirkaldy's testing works, some of these bricks, taken from stock three years old, carried a pressure of 21 tons before crushing, whilst others only four months old crushed with nine tons pressure, showing not only great toughness, but also that they greatly improve by age.

There are now two machines fully employed, making about 130,000 bricks weekly, consuming 250 tons of slag sand and 30 tons of selenitic lime and oxides.

The preparation of this selenitic lime forms a necessary branch of the business. It is made in the following manner:

80 per cent. of unslacked common lime.
10 per cent. of raw gypsum.
10 per cent. of iron oxides calcined.

These are all ground together, under edge runners, into a fine dry powder. The composition is then passed through a fine sieve, 24 meshes to the inch; it is then ready for the brick press. To each thousand of bricks, 6 cwt. of this lime is used: no water is added, sufficient being held in suspension in the slag sand to thoroughly moisten the lime; in fact, it is no uncommon thing to find a stream of water flowing from the brick press which has been squeezed out of the sand.

The loss of bricks in manufacture is very small; in fact, after the bricks are once upon the barrows, the waste is not more than 1½ per cent.

At the present rate of production there is a consumption of slag for this one article alone of about 14,000 tons per annum.

The weight of these bricks is about 30 per cent. lighter than ordinary red ones —9 in. by 4½ in by 2½ in.—weighing only 2¼ tons per thousand.

Another interesting feature in connection with these bricks is the economy in manufacture, which—including all materials, labor, wear and tear of machinery, &c., superintendence, power, and everything, except interest on capital, does not exceed more than 10s. 6d. per thousand.

The following is an analysis of these bricks, made by Messrs. Patterson and Stead, and will be found worthy of notice, showing the hardening properties contained, the composition comparing favorably with the cements previously mentioned:

	Per cent.
Lime	29.90
Silica	25.15
Alumina	21.80
Protoxide of iron	1.44
Protoxide of manganese	0.26
Peroxide of iron	1.66
Magnesia	5.10
Potash	0.53
Soda	0.36
Sulphur	1.00
Sulphuric acid	1.25
Phosphoric acid	0.01
Carbonic acid	2.60
Total water	9.50
	100.56
Less oxygen of the lime combined with sulphur	0.50
	100.06

As before-mentioned, the lime used for making bricks is selenitized, the following being the analysis of the raw gypsum employed in the process.

	Per cent.	
Sulphuric acid	46.18	Sulphate of lime.
Lime	32.32	
Silica	0.35	
Water at 100 per cent	Nil	
Ditto given off at red heat, being water of crystallization	21.00	
	99.85	

The process of brick-making, as now carried on, is extremely simple, and, as already shown, inexpensive; but it was here that the greatest difficulties were met with.

There was no machinery to be purchased that could work the slag sand into bricks, in the state in which it arrived from the blast furnaces. In the earlier attempts the sand had to be prepared in a fine state, the result being a superior class of bricks, but of a cost so great as to exclude them from the market. The author had, therefore, to design and construct brick presses and other machinery that could work the sand, as it came from the slag-sand machines, directly into bricks. The success of this machinery at once rescued the Cleveland Slag Company from an early collapse, but not before a large amount of money had been spent, and some two years wasted.

A description of this machinery is given further on; but, in designing the press, the following points had to be kept in view, viz.: unusual depth of brick moulds, as the sand (being spongy) is exceedingly compressible; great pressure, in order to consolidate the slag; as well as great care in mixing the lime in fixed proportions to the sand—too much lime tending to burst the bricks, whilst too little seriously affects the hardening.

The next product to be described is the manufacture of what is called slag cement. The word cement has sometimes been objected to in connection with this material, because it is generally manufactured in a wet state, and must be used within a few hours after being made. Upon this point the author expresses no opinion, simply mentioning

the fact that, in point of strength, he finds little difference whether the materials are ground together in a dry or in a wet state. The cost of production, however, is, as nearly as possible, four to one in favor of the wet state. It is made by grinding under edge runners, for about one hour (the finer the better), 70 per cent. of slag sand, 15 per cent. of common lime, and 15 per cent. of iron oxides, calcined iron stone, or spent pyrites.

The following is an analysis of this cement, lately made by Messrs. Patterson and Stead:—

	Per cent.
Lime	22.90
Silica	21.61
Alumina	19.85
Protoxide of iron	4.00
Protoxide of magnesia	0.21
Peroxide of iron	8.80
Magnesia	4.36
Potash	0.50
Soda	0.32
Sulphur	1.19
Sulphuric acid	1.54
Phosphoric acid	0.02
Carbonic acid	3.00
Total water	12 00
	100.29
Less oxygen of the lime combined with sulphur	0.59
	99.70

Upon comparing this analysis with that of Portland cement, and the puzzolanas already given, it will be seen that the various hardening ingredients exists in all.

The large quantity of water held in suspension in the slag sand is quite sufficient to make the mass in the mill into a semi-fluid state, but this water is mostly taken up in setting, as water of crystallization. It is, therefore, necessary that the cement should be used before setting takes place. This cement is usually employed for making concrete, by mixing one part of the cement to five parts of slag shingle. The shingle is made by the slag-shingle machine before described.

The shingle, before being used, is well wetted; and when the concrete is put into place, it is beaten lightly down in a soft state, until the water and cement begin to rise on the top; two days afterwards it has become sufficiently set to allow of the building boards being taken down, and at the end of a week it will be fairly hard, and will go on hardening for months. It is perfectly hydraulic, and will harden under water. It will be seen by this that it requires longer time to set than Portland cement, and is perhaps not quite so hard; but there is a remarkable toughness, which has surprised all those who have used it, and this toughness makes it valuable for heavy machinery foundations, &c.; and, when made in proximity to the furnaces, the cost of the cement will not exceed 6s. per ton, whilst concrete made of this cement and slag shingle will cost only 5s. 6d. per cubic yard.

These prices are absolute figures of cost, that of the concrete being arrived at after having executed many hundreds of cubic yards, both upon the Tees Iron Works, at the new railway station at Middlesbrough, and elsewhere. The Slag Works' buildings, the walls of which are between 70 and 80 feet high, are built entirely with it, the basement walls being 2½ feet thick.

Whilst the underground walls of the Slag Works were being executed, they were twice immersed, through exceedingly high tides, with the result that this part of the building is the hardest of all; and to give an idea of the strength, the author may mention that it was necessary, about eighteen months ago, to cut two openings at different points through the basement walls, 3½ feet wide and 6 feet high. This employed two good workmen, with steel bars and sledge hammers, at least four days for each doorway.

The author knows of no material at a similar cost which can compete with it, and he is satisfied that it has only to be widely known to be more extensively used. Personally, where time can be given, he employs nothing else for all heavy foundations for rolling machinery, for which purposes, a conglomerate or monolithic mass, it is peculiarly adapted. Slags from the furnaces making Bessemer iron are better adapted to this cement even than those from the Cleveland ores.

Mention has been made of the necessity of keeping the products from slag sand in a damp state for a length of time after manufacture, in order to give them time to harden, or, in other words, to

allow the material to absorb or take up as much water as will chemically combine with the lime, silica and alumina; but whether this water becomes water of crystallization, or water of hydration, or a combination of both, is not at all certain. The author is, however, strongly, impressed with the idea that water in a fixed state, more particularly in a compound state, plays by far a more important part in the setting of cements than is generally supposed; that the presence of water in a chemically combined state forms as much a constituent part of cement as does the lime, silica, and alumina, seems certain from the results of the analysis shown further on. For instance, if Portland cement be heated to a red heat, so as to evaporate the fixed water, the cement loses at once its strength, and becomes rotten. Again, with gypsum, where the water of crystallization amounts to more than one-fifth of its bulk; if this is driven off at a red heat, we have little better than a powder left. And its seems clear that the quicker this crystallization takes place, the quicker is the setting; and on the contrary, as in the slag cements and the brick, the slower the water is in becoming fixed the slower is the hardening, thus showing the necessity of keeping them damp during the process.

At the author's request, Messrs. Patterson and Stead have made many analyses, with the object of testing this point. Samples of Portland and Roman cements were mixed with water in the usual way, some specimens being supplied by the cement manufacturers themselves, as test pieces from their works, and had consequently been under water for various periods. These were all reduced to powder, and carefully dried by keeping them for several hours at a temperature of 212° Fahr., so as to evaporate every particle of free mechanically mixed water. A very careful determination of the chemically combined water was then made, with the following interesting results:

COMBINED WATER.

Four days in water.		Six days in water.	
Portland.	Roman.	Portland.	Roman.
5.75%	5.25%	6.8%	6.78%

Seven days in water.		
Portland.	Slag cement.	Slag brick.
7.75%	10.50%	5.70%

From this it seems certain that the hardening follows closely in proportion to the quantity of water which becomes chemically combined, and that the slag cement undergoes a similar change to that which takes place in Portland or Roman cements. That other chemical changes take place there seems also to be no doubt, but what these changes are, the author leaves it to wiser heads than his own; he only wishes to show that with Portland, or Roman, or slag cement—time being left out of the question—the same chemical changes do take place.

Mortar for building purposes is also another material supplied at the Cleveland Slag Works. It is simply made by grinding the slag sand with about six per cent. of slaked lime in an ordinary mortar mill, and (if ground fine) makes a far better mortar than is generally employed by builders. Two years ago there was a very large demand for this material in Middlesborough, but the building trade has so completely come to a standstill, that at the present time not much is being used. There is only one objection made to it, viz., that it sets too quickly. Mortar supplied on the Saturday, left unused, would be worthless on the Monday. As with the other slag products, its remarkable strength and cheapness combined makes it much liked by those who, in close proximity to the works, can obtain it freshly made.

One other manufacture from slag is carried on at the Cleveland Slag Works, which, although it does not consume much, is still of interest, viz., artificial stone. It is moulded into chimney pieces, window-heads and sills, balustrading, wall coping, and other ornamental work for builders, as well as for paving for footpaths, stables, &c. The stone is composed of two and a-half parts of finely pulverized slag, and two and a-half parts of ground fire-brick, to one part of Portland cement; the mixture is run into moulds, and sets quickly, the articles being ready for the market in five or six days.

In a works where so many special manufactures have been developed, the arrangement of the building—the design, position, and working of the machinery at present used—must necessarily have been arrived at only by hard-earned ex-

perience; and the author has thought that this paper would be incomplete without a description of the factory at Middlesborough, with such further modification as an experience of five years' working has suggested.

The building is constructed of slag-cement concrete throughout; the main building has four floors, the size of which are 46 feet by 33 feet, whilst the slag-sand stores, gantry, engine house, lime house, &c., occupies 97 feet by 47 feet. The slag sand is brought from the blast furnaces in large wooden railway trucks, holding between seven and eight tons each, and is run up an incline by the locomotive into a gantry. The bottom doors of the trucks are opened, and the slag sand is dropped or emptied into hoppers below. These hoppers are capable of holding about 600 tons of slag sand, or storage enough for one week for three machines, and should be kept constantly filled. From these hoppers it is drawn into large wheel barrows, and is taken up by a double-acting hoist to the top of the building.

This hoist is driven from the main shafting in the mill, and is worked by two belts, one crossed, the other open, for the purpose of reversing the cages. The cages can be made to stop themselves at any floor, and have a self-acting brake to prevent any movement of the cages after the straps are thrown off, the action being most simple and effectual.

The sand barrows are taken from the hoist at the top of the building, through a passage, and tipped into the hopper, which supplies the brick presses. Selenitic lime is fed into a small hopper, by hand, from a chamber or floor above. At the bottom of these sand and lime hoppers are the measuring apparatus, which accurately measure both the lime and the sand in the exact proportions necessary. From the measuring drums, the material falls upon sifting and mixing apparatus from which it falls through the floor into the brick press. This press has been designed especially for the purpose, and has many new points. It is of immense strength. The pressure is obtained by two cast-steel cams, which are fixed upon a forged steel shaft $7\frac{1}{4}$ inches in diameter; this shaft, resting on bearings between two strong frames, is put in motion by very powerful double-geared spur wheels, the first motion shaft having a heavy fly-wheel upon it to steady and equalize the pull upon the strap. The pressure cams act against rollers fixed upon two steel cylinders, or rams. These rams transmit the pressure to the moulds under the table. The table is circular, and contains six pairs of moulds, so that four bricks are pressed at one time, the table remaining stationary during the operation. At the same time the bricks are being pressed, two other pairs of moulds are being filled up with material, whilst the other two pairs are delivering up the four bricks already pressed at the previous revolution of the cam shaft. The bricks are pushed out of the mould by smaller pistons, which are acted upon by separate cams. The moulds are lined with changeable steel plates three-sixteenths of an inch thick, and the sand and lime is fed into two pug mills. These pug mills are fitted with six knives each, so as the more thoroughly to mix and chop the spongy slag with the lime. The table is shifted round by a kind of ratchet motion. Immediately above the pressure-cylinders are two pressure-stops, which are held down by the heavy-weighted levers. These levers therefore, receive the whole pressure put upon the bricks; and, in case there should be too much sand getting into the moulds, they simply lift up and relieve the strain. The weights can be weighted at option, and thus form an exact gauge of the pressure upon the bricks. The moulds are generally filled so as just to lift the levers in ordinary work. The filling is easily regulated by the set of the knives on the pug shafts, which press the material into the mould and one side of the pug-mill cylinder is made to open so that the knives are accessible at any moment.

The pug mills are filled by means of measuring and mixing apparatus placed on the floor immediately above the brick press. The mixing and measuring apparatus is very simple and efficient, and works without trouble. The slag sand is tipped into a hopper by large barrows, which are lifted up by a hoist. At the bottom of this hopper there is a revolving cylinder, with ribs cast upon it, which, revolving under the hopper, carries a certain thickness of sand, the thickness having been previously regu-

lated to the requirements of the press. The slag then falls upon a sieve, which separates any large pieces of slag in a solid state, and at the same time allows the falling sand through the sieve to fall like a shower. The lime is fed into a separate hopper, and is regulated by a feed-roller of smaller size. The lime then passes down a shoot, which forms part of the slag-sand sieve, where it meets the shower of sand—falling together with it—thus getting thoroughly mixed. On the right-hand side of the slag gantry and hoppers is the mill for preparing the selenitic lime. The lime, after being ground under edge runners, is passed through a sifting apparatus, the wire of which has 24 meshes to the inch; it then falls into a hopper, is taken by barrows through a passage to the hoist, and lifted to the lime chamber, before mentioned. In a line with this mill, and parallel with the slag gantry, are the stores for the lime, gypsum, and iron oxide, whilst behind the lime-house are the engine and boiler.

The hardening sheds are three in number, and should be each about 100 feet to 40 feet. The floor must be perfectly smooth and level—this being an important point—as an uneven floor spoils the bricks. The sheds should have plenty of ventilation, and require to be cool in summer. Great care is necessary in stacking these bricks, as they come off the barrows. They are placed on edge quite close together, and stacked six in height, and when once here in position, there is little or no loss afterwards.

A material containing so much lime, silica, alumina, sulphur, and magnesia, in a condition like the white soft slag sand, suggested its application as a fertilizer for some kinds of lands. Three years ago, through the kindness of Earl Cathcart, it was brought before the Royal Agricultural Society, and Dr. Voelcker reported "that the result of his examination shows that it may be usefully employed upon moorland and peaty soils as a cheap and effective substitute for lime."

Since this report was made, many hundreds of tons have been sold for this purpose, and although there was only 32 per cent. of lime in the slag supplied, the results have been very satisfactory, particularly on land growing potatoes. Had it been Bessemer slag, containing from 40 to 50 per cent. of lime, there cannot be a doubt but that the results would have been still more satisfactory, and the author feels sure that it must, in some localities, find a large outlet for this purpose.

Mr. Frederick Ransome, M.Inst.C.E., the well-known inventor of the artificial, siliceous stone, has recently taken out a patent for mixing the slag sand in its wet state with chalk, and then burning the whole together in a cement kiln into clinker, after which he grinds it down in the same way as Portland cement. The results given are most remarkable, exceeding Portland cement in strength by nearly 30 per cent. The experiments are of so recent date that the author has considered it better not to give any further statistics.

A sort of concrete brick has, during the last few years, been made at the Moss Bay Iron Company, Limited, Workington, from hematite Bessemer slag, under the direction of Messrs. Kirk Brothers, Mr. Henry Hobson being the then manager, and, I believe, the originator of the process. These bricks have been made by a process differing entirely from the system adopted by the author at Middlesborough, and already fully described. The slag employed at Moss Bay is pulverized from the cold solid slag, under massive edge runners, which crush the material into fine dusty shingle; it is then lifted by elevators into French burr stones, and ground down as fine as sand. From the stones it passes through a worm conveyor to a brick press, during which about 25 per cent. of common river sand is added, with sufficient water to thoroughly damp it, without any addition of lime, again showing, in a remarkable degree, the extraordinary setting nature of the slag, after the chemical combination with the water and exposure to the air has taken place. These bricks are taken from the press, and placed under cover for a few days, when they are put out in the open air to harden. The bricks are of excellent shape, grey color, and become exceedingly hard, as will be seen from the specimens exhibited. Large quantities of these bricks have been employed in building the Moss Bay Steel Works, and

appear to be standing remarkably well. The cost, however, is very heavy, owing to the difficulty of preparing the slag, and the wear and tear of the machinery; the excessive weight also precluding the sale at any great distance from the works.

The large amount of lime, combined with the silica and alumina in the Bessemer slag, as seen in the analysis already given, quite accounts for the setting properties. With the exception of the bricks used upon the works, the author believes that there has not been any large quantity made, and the machinery has now been standing many months. The process is, however, again another proof, in a very interesting way, of the peculiarities of the material. The bricks continue to harden for years, and appear to arrive at a kind of crystalline fracture, which damp greatly accelerates. There is no doubt whatever that if this slag were treated by the process adopted by the author, that bricks, in every way superior to the ones thus described, and, from the nature of the slag, superior, even as a building brick, to those produced at Middlesborough.

There remains, now, only one more application of blast furnace slag for the author to trouble you with. It is the manufacture of slag wool, or silicate cotton, so-called from its resemblance to cotton-wool. The first attempt at this manufacture was in 1840, by Mr. Edward Parry, in Wales, and a large quantity was made, but no effort appears to have been made to confine the wool after production, consequently it floated about the works with the slightest breeze, and became so injurious to the men that the process had to be abandoned.

About four years ago Herr Krupp, of Essen, and a little later, Herr Lurrman, of Georgmarienhutte, in Hanover, both supplied a great deal to the market, but the precise method of manufacture has never transpired, having been kept a secret at the works; and until two years ago it has never been successfully made in this country.

As carried out by the author at the Tees Iron Works, the process is exceedingly simple; a jet of steam is made to strike upon the stream of molten slag, as it flows from the usual spout into the slag wagons or bogies. The steam scatters the slag into shot. As each shot leaves the molten stream, it draws out a fine thread, just in the same way as when you touch treacle lightly with the finger; if you lift it up you will see a fine thread attached. The consistency of molten slag is not unlike treacle; each shot makes a fine thread which, losing its heat, becomes set like glass. The shot being heavy, drops to the ground, but the thread is sucked into a large tube by an induced current of air, caused by the steam jets, and the wool is discharged into a large chamber. The finer qualities float about and settle near the outside, whilst the heavier or larger fibres lie chiefly in the center of the chamber. After each blowing, the chamber presents a most remarkable and curious, as well as a beautiful appearance.

The wool, as will be seen by the specimens shown, is of snow-white color, and attaches itself to the sides and roof, or to anything which it can touch, in the same manner as a light fall of snow does in calm weather upon every tiny twig of a leafless tree. The wool is taken up daily with forks, and put into bags for sending away. It is principally used for covering boilers or steam-pipes, for which purpose it is peculiarly adapted, as being a splendid non-conductor of heat, and incombustible. About four tons of this wool is produced per week, and, as only one quarter of a cwt. is made from each ton of molten slag operated upon, you will see that the process is not a very rapid one.

In conclusion, the author hopes that the progress which has been made during the last few years towards the utilization of this hitherto neglected material may induce others to assist in converting it still further into what is useful to man, and in place of being an incumbrance and a nuisance, continually encroaching upon valuable land, it will more and more assume a condition of value.

French Railways.—The new railways now under contract will increase the French lines from 22,193 kilometers to 40,000 kilometers. Most of the work will be done under the superintendence of the government agencies, and the lines will be managed under state supervision, but not at government expense.

THE PRESERVATION OF IRON SURFACES.

From "The Engineer."

About two years ago two processes were described for the protection of iron surfaces from rust. The first referred to is that of Professor Barff, the second is that of Mr. George Bower, of St. Neots. The result sought to be attained by both inventors is the same, namely, the formation on the surface of the iron of a coating of magnetic oxide of iron, but the means adopted are different. At the time referred to Professor Barff had already attained considerable success, while Mr. Bower's process was still immature and undeveloped. During the two years which have since elapsed, Mr. Bower has worked hard and overcome a great many difficulties, and his process is now so far complete that he can produce the results he aims at with uniform success. We do not know what Professor Barff has recently effected, and we can only compare Mr. Bower's practice of to-day with that of Professor Barff's of two years ago; but it is certain that he has succeeded in doing that which Professor Barff could not do then, and the whole process is at once simpler, cheaper, and more manageable than that of the Professor.

The magnetic oxide of iron is a substance whose nature and mode of formation is not quite well understood. It is assumed by chemists to have the formula $Fe_3 O_4$, but some doubt has been entertained concerning its accuracy. In order to produce the oxide, it is essential that the oxidation of the iron shall take place at a high temperature, and that only a limited quantity of oxygen shall be present. The Barff process consists in placing the articles to be coated in an oven or furnace sealed up air-tight with clay. In this they are heated to a cherry red, a current of very highly heated steam is then turned into the oven; the superheated steam is at once decomposed; the iron seizes the oxygen, while the hydrogen is left free and discharged by a small pipe into the furnace. The quantity of oxygen can thus be minutely regulated by controlling the influx of steam. Mr. Bower began operations by using air alone, and one of his first experiments was the heating of a bar of iron, 1 in. square and 8 in. or 10 in. long, in the tunnel from a hot blast stove to the tuyeres. The temperature of the air was about 1500 degrees. The bar became very strongly coated with a kind of brown oxide, and although it has since been exposed to all weathers, no corrosion has attacked it. Mr. Bower next tried heating the iron to be coated in gas retorts, and admitting fresh air to these retorts only about once in two hours. Curiously enough the first experiment he tried was perfectly successful, though about thirty subsequent experiments were failures. Had the first been a failure he would very likely have abandoned the pursuit, but its success encouraged him to proceed. Aided by his son, Mr. Anthony Bower, he persevered, and after the expenditure of much time and money he succeeded in devising means by which, as we have said, uniform results can be obtained. The magnetic oxide of iron appears to be always a secondary product; that is to say, the sesquioxide $Fe_2 O_3$ is formed first, and subsequently $Fe_3 O_4$, or the magnetic oxide, which, by the way, occurs "natural," is a valuable ore, and is the "loadstone" of old books. Availing himself of this fact, Mr. Bower first coats his iron with the ordinary oxide, and then converts this into the magnetic oxide. The process is extremely simple. An oven is constructed large enough to contain, say, a ton of the articles to be coated. In connection with this oven is a gas producer, somewhat similar to Siemens'. Any required quantity of air can be admitted, the air being previously heated to a high temperature, to the oven, which accordingly can be filled either with carbonic oxide from the gas producer, or with carbonic acid, or with carbonic acid and an excess of oxygen at pleasure. After the articles have been placed in the furnace, air mixed with carbonic oxide is freely admitted for some time, the car-

bonic oxide C O taking up another atom of oxygen from the air and becoming C O_2 with evolution of heat. The excess of air in the furnace or oven supplies oxygen to the iron, which becomes coated with $Fe_2 O_3$. After a time the supply of air is shut off. The carbonic oxide then apparently abstracts oxygen from the iron, and $Fe_2 O_3$ becomes $Fe_3 O_4$, the wished-for oxide. Curiously enough, and for some unexplained reason, the most uniform results are obtained, not as might be supposed by first establishing a coating of red oxide of the required thickness, and then converting it all at once, but by admitting and shutting off air alternately at regular intervals throughout the process, which lasts from eight to ten hours. The consumption of coal is about 5 cwt. per ton of small castings coated. No skilled labor is required, as even if too much air is admitted no harm is done. The only duty devolving on the attendant is to fill the oven, to lute up the door, to attend to the gas producer, and to move a handle between two fixed points half a dozen times in the ten hours. Any handy furnace-man could learn how to work the process in two days.

As for the results, they are eminently satisfactory. To say that the black oxide is indestructible under ordinary influences of the weather is to state a truth known for many years to chemists. The articles which we have seen have a coating of this oxide, not existing there as a scale, but apparently incorporated with their substance. It would be but waste of time to point out the enormous advantage that will accrue from rendering cast iron castings as incorrodible, for all practical purposes, as gold. The end would be worth attaining at some trouble; but in the Bower process there is really no trouble. It will be remembered that Professor Barff found it necessary to scrub, wash, and pickle in dilute sulphuric acid, each article to be coated. In the Bower process nothing of the kind is required; the articles may be taken just as they come from the foundry, and they are none the worse for a thick coat of rust. For example, old lamp posts, which have stood out in the rain unpainted, iron pipes stacked about a yard for years, sewer traps, gas pipes, all go alike into the oven brown with common rust, and come out coated with the magnetic oxide. We have seen a 4 in. gas pipe which had been broken in two; one-half was coated, the other was not, and, when put together, at first sight it seemed as though one-half had been painted lead color, while the remainder was left in its original state. The power of converting the sesquioxide into the magnetic oxide is a peculiar and special advantage of the Bower process, and it is not easy to overrate its value. As some of Mr. Bower's foreign patents are not yet complete, we forbear for the present to illustrate the oven and gas producers which he uses, and about which there are certain ingenious features of detail which are essential to its successful operation. With a properly constructed furnace, there is, as we have said, no difficulty in producing uniform results with comparatively unskilled labor, and the whole cost of the process is so small that its use cannot fail to extend rapidly. The experimental apparatus at St. Neots hardly deserves the name, as it is a full-sized oven capable of containing at least a ton of iron. It is not necesssary that any care should be taken in placing the articles in the oven. The oxide is formed no matter how the articles are piled on each other. It is a curious fact that a chalk mark put on the iron before it is placed in the oven is found a chalk mark still when it is withdrawn, but the magnetic oxide is under the chalk. The special feature of the process is its simplicity of application. For a very moderate sum cast-iron can be rendered indestructible with certainty and dispatch. It is a fortunate circumstance that the color of the oxide, resembling lead, is far from unpleasing. The process would never have been popular had magnetic oxide been a brilliant red, or a dingy orange hue.

Some of the coated articles have been exhibited at the present meeting of the Iron and Steel Institute, and one of the exhibits is a length of rusty angle iron cut in two, one part left rusty as it was before, the other as it has been converted by the process, and the result is very striking. An umbrella stand is not only rendered incorrodible, but it is made, so to speak, "beautiful for ever," as it requires neither painting nor bronzing, and is, in fact, almost like a new

metal. Pots and pans have been coated with the process. Messrs. Smith and Wellstood, of Glasgow, the well known makers of American stoves, sent to Mr. Bower a furnace pan to be coated, and we cannot do better than use their own language in speaking of the result: "We take great pleasure in telling you that in our own judgment your process of oxidizing the surface of iron manufactures is a complete practical success in preventing the slightest appearance of rust. We have had in use and under test in every way we could think of for the last six months one of our portable cast-iron farm and laundry boilers—a 22 gallon size—coated by your process, and not a sign of the least rust or the slightest discoloration of pure clean water has any time shown itself, although the said boiler has several times been standing out of use with portions of water in it to induce rusting. Another test we have given it, and which satisfies us of its value, is by several times firing the boiler with only a small portion of water in it, thereby exposing all above the water-line to a strong heat, and without any perceptible injury to surface coating, and this is certainly what neither the galvanizing nor the enameling process would stand." Mr. F. J. Evans, the engineer of the Beckton Gas Company, gives similar evidence, and Mr. Joseph Kincaid, the tramway engineer, had a large quantity of stable fittings coated by the process last year, and he speaks in the highest terms of it, so that there is now no question of the success of the process after three years of incessant labor, under, at times, the most discouraging circumstances, and after great expenditure of money. It has grown up from a laboratory experiment to a process ready for application to industrial purposes, and fully entitling it to the favorable comments which we have passed on it.

IMPROVEMENT OF THE WATER SUPPLY OF LONDON.

From "The Builder."

THE electoral struggle, on which the eyes, not only of England, but also of Europe, have been fixed with unexampled anxiety, has for a season diverted public attention from the great question of the water-supply of London. But this question will naturally be one of the first to come, in one shape or another, before the new House of Commons. There are signs in the air that various schemes, if not yet ripe to hatch, are in process of incubation. We have already seen, on more than one occasion, how great is the advantage possessed by those who come forward with a thoroughly-studied subject, over those to whom the study is new. And we are desirous that those who are, after all, the persons most deeply interested in this important question—namely the inhabitants and ratepayers of London—should not again suffer from a surprise.

We are convinced (and shall be able at the proper time to show good grounds for conviction) that so far from the three great requisites of adequacy, purity, and cheapness of supply being conflicting elements, no sound and well-considered scheme can be produced that shall advance either one of these objects without at the same time advancing the other two.

Public works in England, as a general rule, have been hitherto carried out on one of two opposite theories. The one is the theory of monopoly, the other that of competition. Each of these theories has its own advantages; each has also its disadvantages. Under a monopoly the expenditure of capital is likely to be restricted rather than excessive. Duplicate expenditure is avoided; economy is studied; but the public convenience is rarely fully consulted, and scientific and practical improvements are but slowly and grudgingly adopted.

Under the principle of competition this is reversed. The outlay of capital is apt to be wasteful; it is often two or three times the needful amount. Working cost is thus inevitably increased. On the other hand, the public convenience is so far studied as may serve to attract custom to one rival rather than to

another. Competition, involving the necessity of studying every source of economy, with a restricted income, tends to stimulate scientific and practical improvement.

Whether either of the two systems most conduces to the public safety, to say nothing of the public welfare, may be doubted. But the general upshot of competition in England, in matters involving much outlay of capital, has hitherto been combination. This method, by which the combatants agree to divide the spoil of the public among themselves, unites the disadvantages of both monopoly and competition, without necessarily securing the advantages of either. Wasteful outlay of capital, wasteful duplication of working cost, have been incurred. And when one competitor no longer strives to divert custom from another, the convenience of the public is likely to be little more studied than in the case of an original monopoly. In fact, the public, under combination, has to pay interest on a double capital.

Are we, then, at the mercy of these two defective theories? Have we no choice but that of monopoly, tempered by competition, till it gives birth to a more comprehensive monopoly?

We are not of that opinion. We are not of those who would fold their hands and cry, "What can we do?" We hold that there is another principle, and that it is the true theory on which the public works of the future can only be successfully carried out. For monopoly, on the one hand, and for competition on the other, we would substitute co-operation.

We may cite an example of the kind of co-operation to which we refer, in the case of the turnpike roads and highways of England before the introduction of railways. Here the State provided the road, and provided it well, and at a moderate cost. Some 130,000 miles of highway, of which 20,600 were turnpike roads, existed in England and Wales in 1873, affording an average length of 2.24 miles for every square mile of the surface of the kingdom. Of the cost no record has been kept. The writer of the article on the Civil Engineers of Britain in the *Edinburgh Review* of October, 1879, estimates that the sum of £160,000,000 barely represents the cost of the highways of England and Wales, and £220,000,000 that of the 197,836 miles of the United Kingdom.

The maintenance of the chief main highways — the turnpike roads — was effected by the traveling public. When traffic is thick this system acts well. When traffic is sparse it proves an intolerable burden. The abstraction of so much long traffic by the railways, in spite of the enormous impulse which they gave to that traffic, sounded the knell of the turnpike system. The present annual cost of maintenance, exclusive of urban roads, is calculated at £3,200,000 When the traveler is unable to maintain the road, the burden falls on the rate-payer.

In the third place, the actual carrying power was provided by individual effort. Sometimes aid of the nature of a monopoly was afforded to a man of enterprise, as in the case of Mr. Palmer, who introduced that excellent form of mail-coach, which was superseded by railways. Sometimes competition ran wild. There was a time when a traveler could be taken from London to Southampton for nothing—so keen was the rivalry between the opposition coaches. It is true that he had to pay double fare for his return to London. But, on the whole, in spite of various shortcomings, the service of our roads, in 1833, was all that could be expected, so long as horse-flesh supplied the motive power and regulated the speed.

Here, then, the fixed half of the "dynamic pair," the road, was supplied by the State, that is to say by the whole country, and maintained either by the actual travelers, or by the potential travelers, that is to say the inhabitants of the locality. The motive power and plant were supplied by individual enterprise; and the public was well served. The inartificial arrangement had in it the true elements of co-operation, and answered accordingly.

We might easily show how the absence of that gentle control, which should so far aid private enterprise as to assure those who entered upon it against unwarranted and unprofitable competition, has strangled the growth of our railway system, and given to our original railway shareholders barely a third of the return received, with lower fares, by the original railway shareholders of France. We

might point to the great expense at which the French Government is now redeeming one of its few blunders in the legislation affecting the public works of France, namely, the establishment of a monopoly in favor of the Chemin de Fer du Midi by allowing the directors to purchase the Canal du Midi and the connecting waterways. But our present business is with the water supply of London. Here we have first, partial monopoly; secondly, wild and unregulated competition; thirdly, partial combination; and, fourthly, an attempt at the re-introduction of monopoly.

We do not propose to confine our views to general principles. The matter is of such importance to every Londoner that no amount of labor can be too great to obtain an exhaustive knowledge of the controlling elements. And here, instead of offering estimates of what may or may not be occasions or opportunities for future saving of cost, we propose to ascertain what, in every item of cost, is the minimum that at this time is actually paid over the great metropolitan province. On such accurate details alone can be based any reliable estimate of what we may expect as a future minimum burden on the ratepayer, when the true principle of co-operation shall have been brought to bear on a well-organized system of supply.

We need not now go into the history of the original monopoly of the New River Company, in which his most gracious Majesty King James was a sleeping partner, enjoying a half share. Neither will we now pause to tell the tale of competition warfare, of costly Parliamentary struggles, and of the coalition of opposing interests. We take the supply of London as it now is divided among eight companies of various magnitude; noticing here that a mark of the waste of money incurred by competition is to be noted in the fact that out of the 117½ miles of the metropolitan area, six miles are jointly shared by two companies. In other words, the work is done twice, instead of once, over those six miles, and that at the cost of somebody.

Taking the eight areas which lie outside the disputed six miles, we find the next sign of the wasteful cost of competition in the different ratio of capital laid out in different districts. As it is not our aim in any way to affect the market price of the stock of any company, we shall omit the names while giving the most instructive facts. Over one district, then, in which it may be presumed competition has been but feeble, the sum expended by the water company in providing for the wants of the inhabitants has been 2.17*l.* per head. In another, the tale of Parliamentary conflict is briefly told by the announcement that the outlay of capital has been 5.20*l.* per head. Ranging between these two figures, the average outlay of capital per unit of the population served was, in 1877, 3.05*l.* per head. It may be safe to set down ten shillings per head, or one-sixth of the actual cost, to the account of that legislation which permitted, not to say encouraged, a wanton competition.

The returns now annually made to parliament of the accounts of the various companies are of value as statistical data. But they are not in a shape—few Parliamentary returns are—to give their full meaning to the reader. They demand, for this purpose, the work of the expert, For this reason they are but little referred to by the press, notwithstanding the important lessons to be deduced from their figures. It has been our study to present some of the outcomes of these returns in a manner that may be readily grasped by every reader; and after consideration, we have arrived at the conclusion that the best unit of comparison to take is the metric ton of water delivered to the householder, or, at all events, sent into the mains of the company for such delivery.

The largest supply of water that has been delivered in the mains of the companies in any recorded year was in 1874, when it amounted to 34.3 gallons per diem per head of the population. This is equal to 56.8 metric tons per head per year.

The smallest ratio of supply recorded was in 1869. It was 31.4 gallons per head per diem, or very nearly 52.1 tons per head per annum. A ton of water per soul per week, in round numbers is thus an ample allowance, and one from which the departure is not, practically, very great; 37.7 gallons per head per diem for a month together is the highest rate of delivery that we have found

recorded. This was in August, 1873; 29.4 gallons per head per diem is the lowest monthly average within the last ten years; that was the rate in December, 1869, and also in December, 1876. It follows that the ton of water delivered is an unusually equable unit for calculation.

Now if we allow only 5 per cent. on the capital laid out (in works and also in Parliamentary costs) by the various companies, we find that it amounts, in the case of the largest capital outlay, to 1.325d. per metric ton of water delivered; and in the case of the cheapest provision, to no more than .530d. per ton. These figures do not coincide with the capital cost per head, because there is a considerable variation, amounting to as much as 40 per cent., between the quantity of water per head supplied by different companies. It is probable that this difference closely represents waste; but we give it as it stands. It is worthy of note that the difference between the quantity of water supplied by the companies delivering the largest and the smallest mean per soul, is very nearly identical with that between the maximum and the minimum supplies of the average of the eight companies taken all the year round.

The minimum charge per ton of water incurred for capital in any case is .63d. per ton, a figure which would be reducible to .53d. per ton if only 5 per cent. were paid on capital. The average charge for capital is about .893d. per ton; and the maximum rises to 1.45d. per ton, or within a fraction of the mean total price of 1.475d. per ton charged all round and covering all expenses. But the highest price per ton is received by the company which supplies the smallest tonnage per head; so that this really lucrative return is no doubt in a great measure due to the prevention of waste.

We shall therefore not be very wide of the mark if we allow the price of six-tenths of a penny per ton of water delivered as one which should be regarded as the normal maximum to be kept in view for London for interest on capital. This, however, is without prejudice to a plan for a future extinction of such capital. In round numbers, the actual charge is half as much more, or .9d. (exactly .803d.) per ton.

As to working expenses we must first consider those which, under any system of management, are directly proportioned to the quantity of water delivered in the mains. That, as we have before hinted, may possibly be a very different quantity from that delivered in the houses. These items are pumping and filtering. Their cost is influenced, in no small degree, by the difference of level between the source from which the water is taken, and the height of the ground over which it is delivered. Thus, while the cost of the two items, averaged for all the water companies of London, is .183d. per ton, it rises to the maximum of .234d., and sinks to the minimum of .085., chiefly owing to differences of level. There is reason to suppose that, over a certain and a not inconsiderable area, the pumping expenditure might be reduced by a better mode of districting. On the other hand, the cost of filtering ought rather to be increased than de creased. And the due provision for supply under pressure in case of fire is a provision that may enhance the cost of pumping in some cases. We ought not, therefore, to set down this mechanical cost at less than the present average of .183d., or, in round numbers, two-tenths of a penny, per metric ton of water delivered to the consumer.

Management varies from .076d. per ton (in two instances) to .167d. and .170d. per ton (in two others). The wealthiest companies pay the most for management. The average charge is .119d. per ton. There does not seem to be any reason why, if the whole system were arranged in the best possible manner, the cost of management should exceed eight-hundredths of a penny per ton of water.

Maintenance, and and all expenses but those before mentioned, cost, on the average of the eight companies, .280d. per ton. The lowest rate is .209d.; the highest, .414d. The price of .249d. is the lowest but one; and we may probably be justified in taking that figure, or say .25d. as a normal price and under a perfect system of management.

We thus have the following elements of cost as they may be ranged under the system of monopoly, competition, and scientific co-operation:

COST PER METRIC TON OF WATER.

	Government Bill.	Actual.	Possible.
Dividend and Interest...	1.500	.900	.600
Pumping and Filtering...	.200	.200	.200
Other working expenses.	.225	.225	.250
Management and Collect'n	.120	.120	.080
	2.075d	1.475d	1.130d

The decimal of other working expenses are, it will be seen, reduced by our taking the other items in round figures.

We have here before us, far within the limits of practical accuracy, a conspectus of the cost at which a ton of water may be delivered to the consumer over the metropolitan area. The actual average price of three-halfpence cannot be considered as exorbitant. It should be noted that the supply per soul delivered by that company which has some sixty per cent. of its deliveries under constant services is four per cent. below the average—and that in spite of a large consumption for trade uses. And we cannot call too much attention to the fact that it is only on the principle of co-operation that an attempt is likely to be made to reduce both quantity delivered and price per ton. As matters now stand only about one-seventh of the cost of the water to the public is affected directly by quantity. As much capital, as much establishment, as much cost of of every kind, except pumping and filtering, or, at least, almost as much, is incurred in the delivery of the 29.4 gallons per head per diem of the winter as in that of the 37.7 gallons per head per diem of the summer. If companies are paid by charge on rental, they will seek to deliver as little water as possible. If they are paid in any way by metric tonnage, they will endeavor to deliver as much as possible. Their interests, in this particular, are not identical with those of their customers.

As to the manner in which the principle of co-operation is to be brought to bear on the arrangement of these complicated interests, we have no space now to enter into the investigation. But we may point out the existence of the elements of co-operative success. First, there is great, certain, and increasing demand. A sound scheme has this sound basis. Under any conceivable circumstances the Londoners are able and ready to take, and to pay what is necessary for, let us say, 26 metric tons of water per head per annum. This is an ultimate fact, and on this fact, not strained, but duly regarded, all calculations must be based.

Secondly, we have the state to a certain extent already concerned in the affair. the State has conceded certain rights, which it is bound to respect, where the conditions have been observed. The State must be the arbiter of what is to be done when those rights have reached their limit.

Thirdly, we have a vast machinery, already provided by competition, the utilization of which will be made more advantageous by substituting the principles of co-operation. It is obvious, to take a single example, that nearly twice as much money must be spent in supplying water to those six miles of area which are jointly supplied by two companies, as would be the case if they were supplied only by one. In the same way any attempt to introduce a new competing means of supply, instead of controlling and consolidating the existing ones, can only end, if it have any success, in laying the burden of extra capital outlay on the ratepayer. It is mainly in that districting by zones of level, which must form a part of any real improvement in the hydraulic arrangements of the London water supply, that, as we have seen, economy is to be effected. At the same time, we regard one chief advantage to be the means of obtaining a perfect control for the extinction of fire.

Again, as to the source of supply. Even apart from any question as to the water of the Thames, the sources of the deep wells at Deptford, at Plumstead, at Charlton, at Crayford, at Shortlands, and at Belvedere; of the Chadwell spring; of the wells at Ware, Amwell, Cheshunt, Hoddesden, and Wormley, and of the river Lea, are acquired to London, and must form a part of any future system of water supply. We have before indicated the green sand underlying the valleys of the Wey and of the Mole as a future source of ample supply of the very purest water. The rainfall over the Wey basin alone amounts to nearly five

times the entire annual consumption of London. Not a third of that runs through the channel of the Wey. Much of what is not evaporated must thus make its way through the pervious subsoil to the valley of the Thames. In 1828, Mr. Telford reported to Parliament in favor of the utilization of the waters of the Ver and of the Wandle. Long familiarity with the district leads us to add the names of the Gade and of the Chess. With sources of supply like these at command, it is worse than idle to talk of saddling the ratepayers of London with prodigious works for tapping the cradle of the Severn or of the Wye, with the result of doubling the present charge for interest on capital—interest which, one way or another, has to come out of the pocket of the ratepayer.

By due co-operation of the State, the companies, and the consumers, we are convinced that it is possible to give to London a constant supply of pure water at a working charge of less than six-tenths of a penny per ton, exclusive of interest on money; and further, by judicious forethought, to extinguish the cost of the capital within little more than half a century, without any increase of the present burden on the rate payer.

PURE WATER.

From "The Architect."

"WATER, water everywhere, and not a drop to drink," or rather, that is fit for drinking, is a cry only too frequent both at home and abroad. From rivers polluted with the sewage of towns the water supply of great cities is often drawn. Wells reeking with surface drainage are relied on in rural districts, and only when an outbreak of typhoid or enteric fever arouses the inhabitants from their lethargy is the death-dealing scourge traced to its true source—impure water.

What is the antidote? Filtration, by some system which shall be not only mechanical, but chemical in its action. This end seems fully attained in the "Silicated Carbon Filter" produced by the Silicated Carbon Filter Company, of Church Road, Battersea. In a recent visit to the works we had an opportunity not only of seeing the material in the raw state, but also the modes of manufacture, and of examining filters suitable for many purposes, from the purification of the water supply of towns to the siphon filter for the use of travelers.

To begin at the beginning, the carbon used by the Company is neither vegetable charcoal, liable to become foul with increase of temperature, nor animal charcoal, prone to generate animalculæ, but a mineral carbon free from the defects of both.

The construction of the silicated carbon filters, though modified in slight details to suit exceptional emergencies, has one fixed basis. The upper and lower layers are invariably slabs of mineral carbon moulded when moist, and then subjected to hydraulic pressure until they become a dense mass, to be finally indurated throughout by the action of fire into hard, solid cakes of homogeneous structure. The middle layer also consists of mineral carbon which has been subjected dry to hydraulic pressure, forming a mass which, from its lesser density, offers minor resistance to the free passage of the water, thus permitting greater rapidity of filtration with equally satisfactory results. The "saggers," destined to hold the mineral carbon slabs, are formed of Stourbridge fire-clay, moulded on the premises into tubes varying in size according to the cakes they are to take, and pierced round with small holes to provide for the escape of gas evolved in the process of firing. In these "saggers" the carbon is packed in granulated carbon, to prevent touching, in various sizes, from the tap or "faucet" filter, in use in the States, of half an inch in diameter, to the filters for brewers' use or the water supply of towns, made of any required dimensions. The necessary number of "saggers" being filled, they are placed in a kiln with two fires, having an inner lining to protect them from the direct action of the flames. In this kiln they are kept at a white heat for some days,

then, the fires being drawn, they are left to cool gradually until their temperature has moderated sufficiently to permit the "saggers" being handled by workmen, whose hands are protected with thick leather gloves. When quite cool the lower slab is fitted into the filter by cement, the dry layer placed over it, and above all the top slab is fitted and cemented down, so that all is made air-tight.

The brickwork of the kiln is banded with great hoops of iron. Opposite the door, built up of fire-bricks, after the kiln has received its full complement of "saggers," and cemented, is a strong bar of wrought iron set tight by a screw. This bar must needs be strong, for the intense heat so expands the brickwork and iron bands that, at the height of the firing operation, it has to bear a pressure of no less than 60 tons. Were it to snap, the whole structure would burst to pieces, and a chaos of mingled brickwork and iron take the place of an orderly array of "saggers," set in rows within a solid superstructure of bricks, built up on foundations, radiating like the spokes of a wheel, set up on a solid bed of cement. This is the process adopted for all the filters. In the brewers' filter there is a third hard slab inserted in the center of the filter, between two soft layers.

Taking the water supply of towns, it seems a strange circumstance that the practical philanthropy of Kyrle, the Man of Ross, of whom Pope sang, should still hover over the place he loved so much, and that the little Hereford town should set a sanitary example to many more pretentious rivals. Some time ago an artesian well was sunk. The water from this is pumped into a reservoir situated on a hill overtopping the town. Lower down this height two "brewers' filters," with double cylinders, are fixed at the level of a second hill, over which the water, finding its level, passes, and thence descends, thoroughly purified, to supply the houses and the local breweries of the pretty town of Ross. The construction of this "brewers' filter," adapted for either high or low pressure, is excessively simple. There are two taps both above and below, the filter being in duplicate, with one pipe for outfall at the back. For cleansing, by simply altering the position of the taps, a reverse action takes place. The water is forced backward from one filter to its companion, and the stream of filtered water sent through carries away any impurities which may have collected on the face of the carbon. They cannot pass through, owing to the indurating operation in the kiln. The filter can be connected with a cistern or reservoir, or attached to the main service pipe. No attention is needed save as before said, an occasional opening of the cleansing taps, and the supply ranges from 100 to 2,000 gallons, or a still larger quantity, according to size. A main-supply filter on similar lines, but with a single cylinder, is specially adapted not only for breweries and distilleries, but for soda-water factories, large mansions, schools, hospitals, dye works—in fine, all establishments where a large and constant supply of pure water is required. It speaks much for the estimation in which the silicated carbon filters are held, that throughout Messrs. Huntley & Palmer's biscuit bakery, at Reading, where two thousand people are employed, these filters are fitted up, no water being used in the manufacture of their various products, which has not passed through silicated carbon.

The latest development of the system is one adapted specially for hospital use, or wherever it is desirable to have a series of separate filters. The filter is fastened upright by a bracket to a wall; the supply enters at the bottom, the filtered water being drawn off from the top, reversing the usual process, the cleansing tap being below. This filter commends itself specially to households where space is an object; for butlers' pantries, still rooms, &c.

So much for the fixed filters. There are many varieties of those which are movable, from the dining-room filter in marbled china to the canvas filter for bullock wagons, or the neat nickel case to be slung over the shoulder of a pedestrian in lieu of an ordinary flask. The dining-room filter, can, when desired, be furnished with an ice compartment, ensuring a constant supply of water, pure and cold. Some can be had of a more expensive kind, made in frosted glass or in a porous clay, acting as a refrigerator, in shape and hue resembling an Etrus-

can vase, from which indeed the model has been taken. These are provided with a movable pan, into which the silicated carbon is fitted. By this means the exterior can be cleansed daily without inconvenience. For table use filters are likewise made in porous clay in two portions, the upper containing the filter, the lower being the ordinary "gurrah," "chattie," or "monkey"—to give their East and West Indian *soubriquets*. For hot climates the "refrigerator filter" has been made; without is the case—within a filter fits, the space between being filled with ice, or salt and water. The tap for the filtered water passes from the interior filter through the outer case. Above is a ring which, being pressed down on a flannel covering, keeps both the water and the cooling medium from contact with the air. The melted ice can be drawn off below when needed by a special tap. This peculiar filter is a favorite at Ceylon, the firm making large consignments to Colombo.

A quaint filter in use in the Havana is cone-shaped. The cone exteriorly being of the indurated carbon; the interior of the dry compressed layer. This is simply slung up in a corner, the water being allowed to drip into a "chattie" beneath. Another filter much used in Cairo and Alexandria, and entitled the "double action," is adapted for rain or muddy water. "Old Nile," sacred river though he is, carries so much of the earth in his composition, that any ordinary filter would soon clog under the deposit of mud left by the turbid water. To prevent this the filter proper is protected by a cap or slab through which the water must pass. The rough impurities are therefore left on the first obstacle, which can be removed in a moment and cleansed with a sponge, and the water is thus doubly filtered before use. The same filter is well adapted for the peculiarities of the great American rivers, where a large amount of earth is held in solution.

For the "rough and tumble" usage that filters are subjected to on shipboard and in barrack-rooms, a hard stone-ware filter is specially made, strongly encased, cover and all, with stout wicker-work, and provided with handles for easier carriage. Filters of this pattern are supplied to the Admiralty, the War Office, and various lines of ocean steamers, including such well found vessels as the "Green line," the ships of Messrs. Donald Currie & Co., and troopships like the *Jumna*.

Another provision for the health of the army is provided in the "ambulance filter." Let any one read about the difficulties of obtaining potable water on a campaign in such books as Chaplain Hare's "Journal," or Archdeacon Coxe's "Story of the Campaigns of Marlborough," or the volumes of the historian of the "Peninsular War," and he will at once see its advantages. The "ambulance filter" is simply silicated carbon fixed in a white metal case, provided with a perforated cover to keep off the coarser impurities. To this is attached a vulcanized india-rubber pole, with a tap. That is all. It cannot get out of order, and is set in action solely by exhausting the air from the tube. By means of these filters the foulest water could be rendered palatable, even were the wells poisoned the water would become innoxious, whether the bane was vegetable or mineral, strychnine, antimony, or arsenic. That this is no mere assertion is proved by Mr. Wanklyn's experiment. He dissolved a grain of strychnine in a pint of water, filtered it through silicated carbon, drank one half of it with impunity, submitting the remainder of it to chemical tests, when not a trace of the poison was discovered.

An equally simple system of purification is supplied in the canvas filter. This is merely a long canvas bag, provided at top with a canvas cover, at bottom with a wooden tap. The carbon being placed in the center, it is only necessary to fill the upper portion, sling the bag, provided with a rope handle for the purpose, to the bullock wagon, and the water is purfied *en route*, while it is kept cool by the porous texture of the material. For verandahs in either the East or West Indies, for huts in the Australian bush, for camping-out parties at home, or at the great Divide when out for "big game," this filter is alike useful and unbreakable. When not in use it folds up flat into but small compass, the weight is a mere trifle, and it is always ready for use.

Having started with the water supply

of towns, and indicated the various uses to which the filters can be applied, we may now describe the smallest modification of the system, or the "siphon filter" for travelers. Its latest form is for carrying over the shoulder, as supplied to the forces in the "promenade militaire" in Abyssinia, to the Ashantee expedition, and to the forces in Zululand. A dainty arrangement, strongly recommended by the Horse Guards for officers' kits, and enclosed in a nickel-plated case, has been specially designed by Major Fraser, R. E. Travelers know by sad experience the danger incurred in drinking the water in many Continental cities. At the expense of a few shillings they may carry a pocket friend with them, at once a safeguard and a convenience.

This, then, is a synopsis of the various filters manufactured by the Silicated Carbon Filter Company at their works. The operations of preparing the carbons —firing and fixing, producing the "saggers," turning the filters and "chatties" in porous clay, packing and casing—are all carried on under supervision, in such a way that defective workmanship is impossible in any of the filters which leave the works.

THE EFFECT OF SULPHATES ON LIME MORTAR.*

From "The Builder."

In the year 1870, the author commenced to experiment on the subject of the effect of sulphates on lime mortar, and finding himself at the beginning of 1879 unable to further pursue his investigations, he decided to submit a paper on the subject to the Institution of Civil Engineers, with a view of enabling others to give the matter their consideration. It afforded him pleasure to find that that body appeared to appreciate his labors, inasmuch as it accepted the paper and set it up in type. However, as twelve months had elapsed and there was no appearance of the paper being read this session, the author determined to withdraw it, and by the kind courtesy of the Council of this Association he is enabled to bring it before the present meeting.

It was observed by Major, now Major-General, H. Y. D. Scott, C.B., Assoc. Inst. C.E., about twenty-five years ago, that the chemical combination of a small quantity of sulphurous acid gas with limes had the effect of causing them to set, after the manner of cements, without increase in bulk or any considerable elevation of temperature. The union of the gas with the lime was first effected by allowing sulphur fumes to pass into the kilns during the process of calcination; but more regular results have since been obtained by mixing either a soluble sulphate or sulphuric acid with the lime after it has been burnt. In ordinary mortar the lime, before being mixed with the sand, is brought to a state of fine division by slaking with water, that is chemically; whereas in General Scott's method mechanical appliances are resorted to in order to reduce the lime to powder, and water containing finely-ground plaster of Paris or other soluble or partially soluble sulphate is then added. When these have been reduced to a creamy paste, the sand is put in along with any further quantity of water necessary to render the mortar when mixed convenient and fit for use. Mortar thus prepared may be used even for plastering purposes shortly after being mixed, as the lime when treated in this manner shows no tendency to slake. The quantity of sulphate required to be added varies with the description of lime, and is much governed by the proportion of clay which it contains. Those limes in which only traces of alumina are found, such as the pure chalk limes, require about 7 per cent., whilst blue lias and other hydraulic limes require but 3 or 4 per cent., and with very clayey limes the amount of sulphate may be reduced to 2 per cent. of the bulk of the lime. The principle of General Scott's invention, now generally known

* From a paper by Mr. Graham Smith, C. E., read at the Annual Meeting of the Association of Municipal and Sanitary Engineers and Surveyors, held at Leeds, on May 27th, 28th and 29th.

as the selenitic process, is so to combine the lime with water that it shall not burst with the heat, and, in fact, to arrest the slaking of the lime so that the setting may take place without increase in its volume. By this means the strength of the mortar is increased, and it is rendered quick-setting, which is a very desirable property under many circumstances. In ordinary building operations, however, the mortar must not be too quick, or it may set before it can be got into the work. A strong, but comparatively slow-setting mortar is often, therefore, to be preferred. The experimental results contained in this paper lead the author to believe that such can be procured by first thoroughly slaking the lime with water, then adding the sulphate to it in that state, and afterwards the sand, ashes, and pozzuolanas, or other ingredients, and mixing the whole in the usual manner. If this method be pursued, and four or five parts of sand be added to one part of slaked lime, a slow-setting mortar will be produced, possessing after having set for some time much greater strength than selenitic or Portland cement mortars containing a similarly large proportion of sand. The characteristics of this mortar are therefore entirely different from those of the latter compositions. It would appear that General Scott entirely directed his attention to the neutralization of the slaking properties of quick lime, and not to the employment of a sulphate with slaked lime, as here proposed, in mixing ordinary mortar.

The adding of plaster of Paris to lime has frequently been said not to be a new process, inasmuch as it has been used by builders for an indefinite period both with and without lime for plastering purposes, in order to produce a fine quick-setting mortar. The proportion of plaster employed for this purpose, however, has always been much larger than that adopted by General Scott, and proposed to be used by the author. The builder has hitherto mixed a large proportion of plaster with lime on account of its quick-setting properties as a material, and employed the resulting composition for rendering the interior of rooms and similar descriptions of work not exposed to wet or damp; and in such positions, were it not for the question of cost, many would prefer to use neat plaster of Paris. This mortar prepared with plaster of Paris if subjected to wet or damp would crack and disintegrate, whereas that which the author advocates is suitable for all situations in which it is customary to employ an ordinary mortar. The plaster of Paris, that is, sulphate of lime, is added in small quantities, because it is the most convenient and economical medium for supplying the requisite chemical constituents. The builder would deem plaster which has been once set as worthless; however, it may be inferred, that if this substance were re-ground, it would answer in the processes which are now being considered nearly as well as fresh plaster of Paris.

In 1870 the author, then having charge of the testing of the various cements and mortars employed in the works in progress at the Liverpool Docks, availed himself of the facilities thus placed at his disposal, to test the effect of mixing sulphates with slaked lime. The results being somewhat extraordinary, it has been thought advisable to bring them in detail before the Institution. The lime used in the experiments, unless otherwise pointed out, was Halkin lime, from Flintshire, in North Wales. The limestone from which this lime is derived contains about the same amount of silica and alumina as that from Barrow, and produces an hydraulic lime, which, however, is not equal to Warwickshire blue lias lime in setting or hydraulic properties. The proportions given in the accompanying tables are in all cases by volume; and where the quantity of any ingredient is represented by a fraction, such is of one part and not of the whole quantity of mortar. The quantity of plaster of Paris in all experiments with Halkin lime was a percentage of the quantity of slaked lime. The various descriptions of mortar tested were mixed in mills on the site of works in progress, and by men daily employed upon such duties; and every endeavor was made to insure that the experiments should be carried out under as nearly as possible similar conditions in each instance.

The first series of experiments was with briquettes having a sectional area of 2¼ square inches, such as usually

made for testing Portland cement. These were drawn asunder by means of a Michele lever cement-testing machine. [The results and all particulars were given in tables.] . . . . It remained to be seen how the addition of plaster of Paris would affect mortar intended to be set under water. Experiments tended to prove that the ultimate strength of the ordinary Halkin mortar was not impaired by immersion in water, but that the strength of the mortar containing a small percentage of plaster was materially reduced. It would appear from these experiments that by adding plaster of Paris to slaked lime the strength of the mortar will be increased and the cost reduced, consequent on the larger proportion of sand which may be employed; and it may be inferred that experience will demonstrate the advisability of employing plaster of Paris in mortar to be used in ordinary building operations, but that it would not be found advisable to add it to slaked-lime mortars intended for hydraulic purposes.

The author does not wish it to be understood that he considers any description of lime-mortar can equal in strength or setting properties neat Portland cement, or Portland cement mortar, in which a small proportion of sand is used. However, when a large admixture of sand is made slaked-lime mortar prepared with plaster appears to be decidedly stronger than Portland-cement mortar containing a similarly large proportion of sand. Even ordinary Halkin-lime mortar, when mixed in the proportions of $2\frac{1}{3}$ to 1, at the age of six months, is about equal in strength to Portland-cement mortar mixed in the proportions of 4 to 1.

It may, on the whole, be taken for granted that mortar composed of four or five parts of sand to one part of slaked lime can be made possessing greater strength than Portland-cement mortar mixed in similar proportions. The economy to be effected is evident when it is considered that the normal price of Portland cement is not less than 2*s.* per bushel, whilst a bushel of slaked lime does not cost one-third of that amount.

The broken portions of the briquettes with which the first series of experiments was made have been exposed to the weather since 1871; those mixed in the proportions of five parts of sand to one part of slaked lime give evidence of being sound material, and of having stood equally well as those mixed without plaster in the proportions of 1 to $2\frac{1}{3}$.

In making mortar the proportions of sand, ashes, and other ingredients which ought to be adopted, depend entirely upon the nature of the lime; for instance, no engineer would put as much sand with blue lias as with gray-stone lime. In the process now proposed similar laws will hold good, but, as a general rule, double the quantity of sand may be used when plaster is added, that would be considered proper with any particular lime under ordinary circumstances.

In conclusion, it may be stated that nearly 800 experiments with bricks and briquettes, carried out in various manners, tend to indorse the general results accompanying this communication and the opinions advanced, which are briefly: that the ultimate strength of all lime mortars will be much increased by the addition of a small percentage of plaster of Paris, and that, when mixed in the manner described, they will apparently at first possess similar properties to ordinary mortar made with the same kind of lime in the manner as at present practised.

PRESERVING STEEL FROM RUST.—The composition of Mr. W. C. Woodhams, of Long Acre, gives good results. It is composed of Russian Tallow, 22 parts; hog's lard, 75 parts; castor oil, 1.25 parts; camphor, 0.25 part; palm oil, 1 part; annatto, 0.5 part; =100 parts by weight. The camphor is first reduced to powder; the lard and tallow are then heated together, and the oils, annatto, and camphor are added, and thoroughly amalgamated. The composition when cool is ready for use; it may be applied by means of a cloth to the substances to be preserved. In some instances other dye or coloring matter may be used instead of annatto. The composition prevents the action of sea-water upon metals. When it is to be used for hot climates, and in order to lessen its cost when it is to be employed for covering large articles, the proportion of lard is reduced, a corresponding amount of white resin and wax being added in its place.

REACTIONS IN THE OPEN-HEARTH PROCESS.

By ARTHUR WILLIS, F. C. S., Landore Siemens Steel Works, Swansea.

From "Engineering."

In this short paper it is not my intention to enter into the details of the construction of the open-hearth furnace, these having been so often and so ably described on former occasions, but to confine myself to the behavior of the metal in the furnace from the time the charge is melted until its completion.

Steel from the open-hearth furnaces, as is well known, can be produced either from:

1. A mixture of pig iron and scrap.
2. Pig iron and iron ore without any scrap.
3. Pig iron, scrap, and iron ore.

All these methods can be employed with advantage, but the most usual is the third—not that there is any special need to use scrap, but because it utilizes all scrap produced during the different stages of manufacture. In the Bessemer process carbon, silicon, and manganese appear to be eliminated uniformly. In the open-hearth process the degree and the time of elimination are quite different.

During the time the charge is passing into the fluid state, carbon, silicon, and manganese are all more or less oxidized, about 50 per cent. of the total amount contained in the charge, varying slightly with the temperature of the furnace.

As soon as the whole of the charge is fluid, the carbon remains almost if not entirely stationary, until the whole of the silicon and manganese are oxidized, which process takes from three to four hours.

During the time occupied by the oxidation of the silicon and the manganese—no gas being given off—the metal in the bath remains tranquil. When the silicon is reduced to about 0.02 per cent., and the manganese has disappeared entirely, the oxidation of the carbon commences, and the evolution of carbonic oxide throws the metal into violent ebullition, described by the melters as "being on the boil." This ebullition continues more or less until the carbon is reduced to 0.10 per cent. or under, when the metal becomes perfectly quiet, and the slag, which half an hour previously had been of a brownish tinge, begins to blacken from a slight oxidation of the metal.

From a number of analyses referring to the oxidation of carbon, silicon, and manganese, during the different periods of the process, I have selected two.

No. 1 was an ordinary pig and ore charge with about 25 per cent. of scrap. No. 2 was a similar charge as far as composition was concerned, but after the pig and scrap were melted sufficient spiegeleisen was added to give by calculation 1.5 per cent. manganese. Samples of the metal in each case were taken every half hour and carefully analyzed with the following results:

No. I.

	Carbon per cent.	Silicon per cent.
1	1.00	1.281
2	1.00	1.118
3	1.00	.506
4	1.00	.326
5	1.00	.232
5	1.00	.046
7	1.00	.020 on the boil
8	.80	
9	.55	
10	.44	
11	.25	
12	.18	
13	.10	
14	.06	

No. II.

	Carbon per cent.	Silicon per cent.	Manganese per cent.
1	1.34	1.60	1.40
2	1.34	.910	.792
3	1.34	.260	.100
4	1 34	.140	
5	1.34	.080	
6	1.34	.023	
7	1.34		
8	1.24		
9	1.10		
10	1.00		
11	.90		
12	.68		
13	.50		

When pure ore is used, no appreciable alterations takes place in the percentage of sulphur and phosphorus contained in the pig and scrap, but of course it is necessary to employ only the purest. Ores containing sulphate of baryta in large quantities are an exception, but it should always be looked for and such ores carefully avoided. In an experiment made with an ore of this description, 30 per cent., of the sulphur existing as sulphate of baryta was added to the metal. Several experiments were made some time ago on a series of charges at Landore from the same cargo of pig iron—a No. 1 hematite—and ores from various districts, no scrap being used in any of the charges, and the following results were obtained:

Name of Ore used.	Sulphur in Pig Iron.	Sulphur in Finished Steel.
	per cent.	per cent.
Elba.....	0.025	0.032
Marbella.....	0.025	0.064
Sommorostro..	0.025	0.025
Mockta.....	0.025	0.025
Tagus.....	0.025	0.064
Soumah	0.025	0.048

To insure that the pig iron was not mixed, samples were taken in each case when the metal was melted, and it was found uniform throughout.

M. Pourcel, at the last meeting of the Institute, stated that steel made from ore charges was unsuitable for plates. I can only say that the whole of these charges were manufactured into plates, which had a breaking strain of from 27 to 29 tons per square inch, and elongated from 25 to 30 per cent. in 8 in.

The pig iron most suitable for the open-hearth process—the sulphur and phosphorus being low—is that containing the least carbon and silicon. In the first place it contains a higher percentage of iron, and, in the second, it does not require to be so long in the melting furnace before the metal is completely decarburized. Moreover, pig iron containing a large percentage of silicon, although it is all oxidized, invariably yields inferior steel. Why, I cannot say. More than 0.50 per cent. of manganese is objectionable, not only on account of the delay it causes, but because of the destruction of the silica bottom by the formation of a fusible silicate of manganese. It is not only difficulties that can be explained, that a metallurgist, dealing with what may be called this mysterious compound steel, has to contend with, but also those which our present knowledge fails to account for. From long experience I find that steel from different brands of hematite pig iron, chemically the same, and made from the same ores, not only act differently in the furnace, taking more time, cutting the bottom, &c., but in their finished state show a marked difference in their tensile and other tests. At first I was inclined to impute this to some defect in the mode of analysis, which failed to detect minute traces of elements, possibly derived from the coke or limestone used in their manufacture; but, in contradiction to this, I found that two cargoes of pig iron of different brands, both of which worked in a most unsatisfactory manner by themselves, gave, when mixed in equal proportions, results which were everything that could be desired. Others invariably gave good results *per se* and, by mixing as many brands as possible, uniform results may be obtained.

Experiments made at Landore show that no metal added to the bath of steel has the slightest effect, as far as the elimination of sulphur is concerned, and manganese is the only metal that will counteract it.

Manganese has been described as a cloak for bad material. No doubt this is so to a certain extent, but at the same time its presence is indispensable in steel made by an oxidizing process. An ingot from a charge composed of Swedish pig iron, and puddled bar made from the best hematite pig containing no manganese, will break into pieces at the first blow of the hammer; whilst a similar ingot, containing 0.08 per cent. manganese, will forge.

Tungsten alloyed with steel appears to harden without detracting from its toughness, but I doubt much whether the advantage gained compensates for the cost. Tungsten is also said to add to the magnetic power of steel, but of this I have no experience. In steel supplied to a Cornish mining company from Sheffield for borers, I found as much as 10 per cent. of tungsten.

As far as fracture goes, this alloy is the most beautiful of all steels.

I have no experience as to the effect of tin on steel, but a bar of iron made from tin-plate shearings, from which the tin had been to a considerable extent removed, was extremely red-short and unweldable; the amount of tin contained in this sample was 0.15 per cent. Lead and zinc, when added to a bath of steel, are simply volatilized, without producing any effect except that of half-choking the melters.

Chromium gives great hardness, but at the same time causes brittleness, and may be put down as useless.

The effect of copper upon steel seems to be greatly exaggerated in most metallurgical works; it is generally stated to cause more red-shortness than the same amount of sulphur. In some experiments made at Landore, it was found that 0.10 per cent. of copper produced no appreciable effect on the quality of steel; and even when the amount was increased to 0.30 per cent., only a slight cracking on the side of the bloom was observeable. This question is, perhaps, more important than appears at first sight. One possible difficulty that soft steel manufacturers will have to contend with will, no doubt, be the scarcity of manganese ores suitable for the manufacture of ferro-manganese, and many good ores might be rejected on account of the presence of copper, a very frequent companion of manganese. At the present time ferro-mangenese containing 5 per cent. of copper would certainly be unsalable, although, in my opinion, it could be used with impunity.

In conclusion, I may remark that any comparisons made by me of the merits of the two great processes for making steel, *i. e*, the Bessemer and Siemens—would doubtless be considered prejudiced; but I believe it is now generally conceded that for soft steel the latter carries off the palm, and this I attribute to the complete elimination of the silicon, to the mixture of different brands of pig, and to the absolute certainty with which the carbon in the finished steel can be controlled.

THE STEEL OF THE FUTURE.

From "The Engineer."

Two parties exist, distinguished by holding different opinions concerning the steel which will be made in the largest quantities in a few years. One of these parties maintains that steel will become stronger and stronger, and that it is not only impossible, but is extremely likely, that in half a dozen years or so it will be stipulated in contracts that steel plates shall not have a less tensile strength than 35 tons to the square inch. The opposite party holds that it is not only impossible to produce a really ductile steel having so high a tensile strength, but that it is unnecessary. Both sides were well represented at the recent meeting of the Institution of Naval Architects, and we have already put our readers in possession of the arguments used, but there is much more to be said on this matter than was uttered in the discussion on the papers by Mr. Denny and Mr. West, and we do not apologize to our readers for returning to the subject, and considering what the steel of the future will be.

Let it be supposed that there is no difficulty in producing trustworthy steels, one of which shall have a tensile strength of 28 tons, and the other a tensile strength of 35 tons to the square inch. It is urged that the first is strong enough for all constructive purposes whatever, and that it is even too strong for all work put together with rivets, such as boilers and ships. So far, it has been found impossible to make a riveted seam—in which the rivets shall be of steel as well as the plates—which will have a greater tensile strength than 19 tons on the square inch of section of one plate. The reason why is very suggestive. It lies in the extreme softness of the rivets. All attempts to make rivets of any but the very mildest steel have ended in disappointment. In order, then, to bring up the strength of the riveted seams of a steel

boiler, let us say, it is essential either to use iron rivets, or to so construct the seams that the sectional area of the rivets shall be about 20 per cent. greater than that of one of the two plates riveted together. It will be seen that if this is done incautiously, the plate will be weakened by loss of material, while the rivets are strengthened. It is not impossible, however, by the use of butt straps, to bring up the strength of the seam nearly to that of the plate; but this involves trouble and expense, and it may be taken for granted that no conceivable single riveted seam—steel plates and steel rivets being used—can have more than 19 tons tensile strength per inch of section, while it is more than probable that the resisting powers of such a seam will be very much less. This being so, either the use of steel for boilers is attended with much inconvenience, or else the advantage supposed to result from the use of steel must be, to a certain extent, sacrificed, But on the other hand, it may be taken for granted that boiler seams which will stand 19 tons on the square inch of strain are strong enough for any required pressure. If, then, we can get this strength by using a ductile metal, with a tensile strength of 28 tons on the inch, why should we use a material which is not ductile, and has a tensile strength out of all proportion to that of the seams which can be made with it? We confess that to us the argument seems to be unanswerable; and it is worth notice that when it was urged at the recent meeting of the Institution of Naval Architects no one tried to answer it. There are, however, purposes for which steel may be used when no riveting is required, and it is not impossible that welding may yet take the place of riveting. Nor is it too much to suppose that boiler rings as much as 14 ft. in diameter, 8 ft. or 9 ft. wide, and an inch thick, may yet be rolled as easily as a 7 ft. tire for a locomotive. If riveting can be dispensed with, then all the advantages of a high steel probably can be realized. We may concede this point at once, and we are then immediately face to face with the question, what are the advantages of high steel? In other words, in what constructive sense is a 35 or 40 ton steel better than a 28 or 30 ton steel?

Dr. Siemens is at once a practical steelmaker, and well acquainted with the use of the metal in its various forms; and he has, moreover, made its nature and peculiarities a special study. He has brought to his work, moreover, a well trained mind and no small scientific acquirements. This being the case, whatever he says concerning steel deserves attention. Now Dr. Siemens has stated that which is tantamount to the assertion that high steel has no advantage over low steel; nay, that low steel is the better constructive material of the two, and he bases his statements on the fact that two steels, the one high and the other low—the one a 30 ton and the other a 50 ton steel, let us suppose—will behave precisely the same way up to a strain of 15 tons on the square inch. Here we may point out that it would be imprudent—and will probably be impossible with safety, because of other conditions apart from the strength of steel—to put a greater strain on any structure such as a bridge than 10 tons on the square inch. But this is well within the limit beyond which high and low steel act different parts. If, then, a steel is never to be strained to more than 10 tons on the inch, it seems as though nothing whatever would be gained by adopting high steels instead of low. But there is another element to be considered. Steel with a tensile strength of much over 30 tons cannot be worked up without annealing. If it is punched, or sheared, or bent in any way, it has to go to the annealing furnace; but, as Dr. Siemens has pointed out, the immediate result of annealing is to take away 20 per cent. of the resisting power previously possessed by the material. A 50-ton steel before annealing is a 40-ton steel after the process. But low steels can be worked without any annealing whatever. It certainly seems absurd to make a refractory metal which cannot be used until it has been brought to the condition approaching that of a low steel. The advocates of high steels will have to look this question all over, and provide a satisfactory answer for it, before they can assert with truth that they have made their case good.

Those who support the claims of mild

or low steel urge that its great ductility is all in its favor. We venture to think, however, that the value of ductility *per se* is very much over-rated. If a bar or a plate stretches 20 per cent. before it breaks, the fact supplies useful evidence concerning the nature of the steel; but ductility is itself a quality very seldom needed in structures. For example, it is totally useless in boiler plates, once they are made and put to work; again, in bridges it is never needed, nor in piston rods, railway axles, or crank shafts. It serves a good purpose sometimes, as far as a mere process of manufacture is concerned. Thus it is useful when the plates of a boiler will not come together quite fair, or when a ship's rib has to be bent. But the occasions on which ductility is of service in the life of a structure are very few and far between; possibly they are all confined to ships—which now and then bump on rocks, or, as in the case quoted by Mr. Laird, on hidden obstructions—and to guns, and perhaps armor plates; for ship plates therefore it may be admitted that ductility is of service, but, as we have said, it is of no service at all in boilers, or bridges, or steam engines, or girders; that is to say, that for such structures a metal which would stretch but 5 per cent. before it broke, would be as good as one which stretched 20 per cent., other things being equal, and might be very much better. For example, a boiler of 50 ton steel plates ought to stand without failure nearly twice as much increase of pressure as one of 28 ton steel, and this argument of the non-utility of ductility is really the strongest perhaps that can be urged by those who favor high steel. It is so good an argument that the high steel party would find it worth while to make some experiments to fully demonstrate its truth. Two girders, for example, one of 30 and the other of 50 tons steel, might be constructed, and loaded and unloaded, in a way practiced by Fairbairn many years ago, and two boilers, one of high, and the other of low steel, might be tested in various ways. The benefits which would be gained if only a 50 ton steel could be used are enormous in certain cases. For example, an entirely new era in bridge building would be opened up if a working load of 15 tons on the square inch, or even of 10 tons, might be adopted in lieu of 5 tons. Marine boilers, again—the riveting difficulty being got over—might be made less than half as thick as they are now. At present, however, neither engineers nor shipbuilders are disposed to give up ductility, but until they do, or at least until they greatly modify their demands in this direction, the high steels have no chance of taking a place in the market as a material of construction. Up to the present, no one has succeeded in making for sale a 50-ton steel with 20 per cent. of elongation, and it is by no means improbable that the non ductility of the metal is essential to its powers of resisting tensile strain. If this be the case, then, the steel of the future must be a mild or low steel, and our own present conviction is that Dr. Siemens is right, and that the efforts of steel makers should be concentrated on the production of a ductile material—in other words, a thoroughly trustworthy 30-ton steel. This will be the steel of the future, unless either of two things can be brought to pass—namely, the abandonment of ductility by the users of steel, or the combination of ductility with a high power of resisting tensile strain by the makers of steel. Neither the one nor the other of these conditions appears to be at all likely to be satisfied for a long time to come. It is well, however, that engineers should consider whether they are or are not too timorous in the use of imperfectly ductile steels for certain structures to the safety of which ductility appears to be in no conceivable way essential.

THE PRESSURE OF WIND.

From "The Architect."

THE following evidence was also given at the Tay Bridge Inquiry, in addition to what was printed last week:

Dr. William Pole, C. E., was examined by Mr. Bidder, counsel for Sir Thomas Bouch. Q. Coming now to the question of wind pressure, explain generally what is known in regard to it? Witness pointed that the question had been thoroughly sifted by Mr. Smeaton in 1759, that engineer having adopted a formula which had since been universally recognized among professional men. According to it, a high wind exerted a pressure of from 4.4 to 6 lbs. on the square foot; a very high wind, from 7.8 to 10 lbs.; a storm or tempest, 12.3 lbs., being equal to a velocity of 50 miles an hour. A great storm would exert a pressure of about 17.7 lbs.; a hurricane, 31.49 lbs.; and a hurricane that could uproot trees and carry away buildings, &c.—a phenomenon which would apply to the tropics—49 lbs. Witness proceeded to say that one of the earliest bridges in which iron was employed with large spans was the Britannia Bridge, which was erected in a locality notorious for its violent storms. In the construction of this considerable attention had been given by Mr. Stephenson to the subject of wind pressure, and in this particular he had been assisted by Mr. Edwin Clarke. A quarter of a century ago the latter gentleman reported that during a violent gale then experienced, the tubes were but slightly affected, although one of them was resting at each end on a pile of loose planks at an elevation of about 100 feet. The lateral motion had amounted to about 1½ inches. The blow struck by the gale was not simultaneous throughout the tube, but had impinged locally and at unequal intervals on all parts of the length which presented its broadside to the storm. On that occasion it was said to be impossible to pass along the tube except by clinging to the windward edge. The remark of the Astronomer-Royal the other day regarding the local and partial character of violent gales was curiously corroborated by this case, as to which he did not think that official had any knowledge. At first, Stephenson adopted a high figure for wind pressure—46 lbs. per square foot—but it did not appear that that had been made use of in designing the bridge, the ultimate calculation being that a violent storm would exert a force of 20 lbs. on every square foot of surface exposed to its direct action. Q. I think from the date of that bridge, down to 1873, there is nothing further to be gleaned from literature or experience to throw any further light on wind pressure? A. I know of nothing more until the Forth Bridge came under consideration. Q. According to your experience, what was, up to that time, the ordinary practice? A. The wind pressure was supposed to be covered by the ordinary margin, particularly in girders of an open character? Q. In 1873, when the Forth Bridge project came under consideration, the proposal was considered of a very exceptional character? A. Yes. Several eminent engineers were consulted, and the investigation of the details of the calculations for the design was undertaken by Mr. Barlow and myself, assisted by Mr. Stewart. Q. In discharging your duty I believe it was felt that the question of wind pressure, having regard to the large spans, required careful consideration? A. Yes. It was with the view of arriving at just conclusions upon that point that the Astronomer-Royal was consulted by Mr. Barlow and myself before reporting on the structure. Q. Is there any point in regard to that consultation to which you wish to draw attention? A. No, I may merely say that we did not rely on his report alone. We went to Greenwich Observatory, and had a long conversation, and the Astronomer-Royal laid before us all his records and observations very fully. He explained to us what he afterwards put in writing, and his explanations were so satisfactory that we entirely concurred in his views. Q. Assuming that the Astronomer-Royal's calculation of 10 lbs. wind pressure per square foot for the Forth Bridge was well founded, do you see any reason why

a different figure should have been adopted with regard to the Tay Bridge? It has been suggested, as you are aware, that the Forth Bridge has longer spans than any individual one on the Tay Bridge? A. The only reason why it should be increased in the Tay Bridge is, I should fancy, the smaller dimensions of the spans, and therefore the greater probabililty of the action of gusts of wind upon these spans than upon larger ones. The dimensions of the Tay Bridge spans must be taken as two spans for the purpose of comparison, because unless the wind blew over two spans it would not exert its full force on one span. These two spans would be nearly 500 feet in length as compared with the Forth Bridge spans of 1,600 feet. In respect of that diminution of dimensions, it was considered proper to make some increase in the force to be provided for. Q. Assuming that 10 lbs. is sufficient for a 1,600 feet span, would the increase due to the lessened dimensions in the case of the Tay Bridge be anything like double? A. I do not know. I have no means of forming a calculation. I confess when I heard that 20 lbs. was estimated for the bridge, that I thought it to be ample, judging from my previous data. Q. Your judgment, according to the knowledge and experience obtainable by scientific men at the time that the bridge was designed, was that it was a structure for which a wind pressure of 20 lbs. was amply sufficient? A. I certainly think so, and I think that that was the opinion of engineers generally, so far as I can guess.

Cross-examined by Mr. Trayner: Q. From whom did you get the information that the Tay Bridge was designed to bear a wind pressure of 20 lbs. per square foot? A. From Mr. Stewart. Q. You say that a higher wind than this would be tropical, as it would uproot the trees and throw down houses. Have you never heard of trees being uprooted and houses thrown down in this country by the wind? A. I have heard of the tearing up of trees, but not of the throwing down of houses. Q. You say that no engineer since Smeaton's time has pointed to a higher pressure than 20 lbs. as being necessary to be provided against? A. I do not know of any. Q. Is Professor Rankine not an authority? A. Yes, I recognize him as a mathematical authority. Q. Well he, in 1866, published a book which deals with the maximum wind pressure, and he says, "In Britain that pressure is about 55 lbs. a square foot"? A. He is not an authority upon that, but upon mathematical calculations. Q. Do you think that Professor Rankine, in issuing under the sanction of his name a rule relative to the ascertainment of wind pressure, was likely to put forward a statement which he had not verified in some way for himself, or ascertained the correctness of it? A. I think he is in error in that. Such a pressure would be a whirl of wind that would apply only to a single stick standing up in the air. I do not believe that any one ever considered such a pressure in building a large structure. Q. Do you know Sir William Fairbairn's book on tubular bridges, published in 1849? A. Yes. Q. Writing to Mr. Stephenson, he said: "If we adhere to our original calculations of 50 lbs. to the square foot for the lateral pressure of wind, we find," and so on. Is not that an instance of an engineer making provision for a larger wind pressure than 20 lbs.? A. Mr. Stephenson in his original design took the high pressure of 46 lbs., but at a later period he adopted 20 lbs. Q. What, in your opinion, was the weakest part of the present structure? A. The lowest diagonal tie. Q. If subjected to a pressure of 40 lbs. on the structure, would it be strained considerably beyond the limits of elasticity? A. Yes. Q. If that diagonal tie was exposed to any such strain on more than one or two occasions, would it not do it a permanent injury? A. It would give it a permanent set, but it would not be more liable to fracture. Q. You agreed with the Astronomer-Royal that 10 lbs. was sufficient to provide for in the case of the Forth Bridge, and you deduced from that that 20 lbs. was ample in the case of the Tay Bridge? A. Yes. Q. What were the conditions which made you think it was necessary to provide for a greater lateral pressure in the Tay Bridge than in the Forth? A. The smaller lateral structure of the former. Q. Did you take into account the different sites? A. No. I think the Forth is exposed to quite as violent gusts. Q. Was there anything else in the construction of the two

bridges that would lead you to a different conclusion as to the amount of wind pressure which each was able to resist? A. The different estimates of wind pressure would be provided for in the construction.

Mr. Benjamin Baker, C.E., who was examined by Mr. Bidder, said: Q. Having regard to the wind pressure alone, and what the bridge had to bear on the night of December 28, what is your opinion as to the wind pressure that the bridge as a whole had to bear? A. I do not think the ruling maximum pressure on that night exceeded 15 lbs per square foot. I think the strength of the structure as it now exists would have been destroyed had the wind pressure exceeded that amount. There are two signal-boxes—one at the end of the bridge and another some distance off. Amongst other experiments I made from time to time I tested a great deal of glass up to $1\frac{1}{8}$ inch in thickness. I have tested the strength of a window with the sash-bars in one of the signal-boxes by placing a ledge round and pumping water on to it until the glass broke. Taking these two things together, I got a very simple rule as to the strength of a pane of glass, and applying that information to the windows here, I found that the effective pressure on the door of the signal-box would not exceed 9 lbs. per square foot, and in the other about double that figure. The pane of glass in the door was 2 feet 3 inches in height by 2 feet wide and $\frac{1}{16}$ of an inch thick, and on the windward side of the bridge. In further illustration of his opinion, witness cited the case of the wooden gable of the Caledonian Railway Station, and a photographer's establishment near the bridge, each of which could not have stood more than 15 lbs. wind pressure. He did not think that the wind pressure over a span of girder exceeded 15 lbs. He had looked for evidence, without success, of any structure capable of bearing 20 lbs. per square foot, which had been blown down. Some years ago, when a good deal of discussion took place about the high pressure to which the Cleopatra's Needle would be subjected, he issued a challenge in *The Times* asking for any case in which a structure had been blown down with a wind pressure above 20 lbs., but had never received a single instance, though he had searched for fifteen years. Q. It has been suggested in this case that the wind upon the limited surface of a second-class carriage might have blown it over. Have you ascertained what pressure would blow a carriage over? A. There are three very well known instances of carriages being blown over in France. They are cited over and over again, and they are the basis upon which French engineers proceed in calculating their viaducts. They all occurred in the same district of France, near the Pyrenees. Two instances occurred on February 27, 1860, one near Salse and the other at Rivsaltes, and the third on January 19, 1863, at Lenchee Station. The carriages were empty at the time they were blown over, and the train was running. In the last case a whole train of seventeen carriages was blown over while it was standing on a siding. The French engineers calculated the wind pressure in the same way as Dr. Pole and others. It varied from 24.2 lbs. to 32.5 lbs. per square foot. On the basis of that result, French engineers since that date had always assumed the wind pressure on a train on a viaduct to be 34.5 lbs. per square foot. This practice is universal in France. I have also heard of a horse-box being blown over in India, and also carriages, but that does not afford useful data, but is only another instance of the fact occurring.

Cross-examined by Mr. Trayner: Q. Do you happen to know that Professor Rankine's basis of wind pressure in Great Britain is 55 lbs. per square foot? A. Well, he may say so, but I think it is of no use, because it is not based on experiments. The appliances for measuring wind pressure are very crude and unsatisfactory, and I do not attach any importance to them at all. Q. On what authority do you proceed? A. My own observation. Q. And you do not value any other man's opinions upon which to rely as regards wind tests? A. Certainly not Professor Rankine's. Q. Why do you object to Professor Rankine? A. Because he is not an original observer. Q. The Astronomer Royal, in his evidence, stated that the wind pressure in Scotland would be 50 lbs. per square foot, and alluding to the con-

tracted valley of the Tay, he thought the wind pressure on the night the bridge fell down may have advanced to 100 lbs. per square foot. What do you think of that? A. I think it is pure assumption.

By Mr. Rothery: Q. You say Professor Rankine is not an original observer. Are you? A. Yes; and I could give you a tremendous number of observations of my own in which I have found that structures have failed at 15 lbs. pressure, and frequently at 13 lbs. Q. What allowance is made for wind pressure in England? A. Every engineer differs from another in his mode of allowing for the wind. There is no fixed limit. Q. What allowance do you assume yourself? A. I assume there may be a wind pressure of about 28 lbs. per square foot, and I make that allowance in the construction.

Mr. Balfour said: Now that the Tay Bridge had fallen, everybody declared that enormous pressure of wind should be provided for, and that Sir T. Bouch should have known of this. But General Hutchinson showed that they had no data to go on, and wind pressure over large surfaces was not taken into account.

Mr. Rothery said it might be taken as universally conceded that engineers did not in practice allow for it.

Mr. Bidder said that they must not draw deductions from the disaster. If the Tay Bridge failed from the wind, it showed, no doubt, that wind might destroy such a structure, but they must accept the testimony as to what was held previously: namely, that no wind pressure sufficient to blow down this bridge need be expected. No man could consequently blame Sir Thomas Bouch for having built a bridge insufficient to bear the wind pressure that came upon it, without blaming far more severely General Hutchinson for passing the bridge on the hypothesis that it was sufficient to bear it. But, in fact, neither of them were to blame. They both acted on the knowledge and experience existing at the time. The question of design narrowed itself to the sufficiency of the piers to resist lateral wind pressure. Now, what amount of this were the piers capable of resisting, and what amount was likely to come upon them? They had it in evidence that the designer thought that to provide for 20 lbs. of wind pressure would be sufficient. No more, they were told on all hands, was necessary. Ought Sir Thomas Bouch to have provided for more? What did the previous knowledge of engineers show ought to have been provided for? In the Astronomer-Royal's report of 1873, he said that in regard to a bridge of gigantic character and daring conception, which was to bridge the Forth by two spans of 1,600 feet, a provision to resist a wind pressure of 10 lbs. was sufficient. That report did not mean that the Forth Bridge, with certain peculiar advantages, would only have 10 lbs. per square foot over its extent of surface, but that any plane surface of this extent would have no more than this to meet. The Tay Bridge, whose girders were continuous, was, he (Mr. Bidder) thought, as advantageously placed for resisting a heavy pressure over a limited surface, as was the Forth Bridge. If the Astronomer-Royal led them astray in regard to the Fourth Bridge, this disaster to the Tay Bridge must be also traced back to him. But, in fact, the Astronomer-Royal's view was the general view of the whole engineering world at the time.

THE STRENGTH OF FLAT STAYED SURFACES.

From "The Engineer."

Although the flat sides of fire-boxes to the number of many thousands are in daily use wherever the railway system is found, very few experiments have been made to determine the absolute powers of resistance of, or the best proportion for, flat stayed surfaces. The sides of locomotive fire-boxes have, as a rule, such a large margin of strength that they seldom fail; and it would appear that little or nothing could be gained by altering the present plan of using $\frac{3}{4}$in. or $\frac{7}{8}$in. copper stays screwed and riveted over, and spaced 4 in. apart center to center.

But there are other flat surfaces besides the sides of the fire-boxes of locomotives and portable engines which need staying. Such surfaces are to be found, for example, in marine boilers; and it will be remembered that a great deal was at one time thought to turn on the construction of a flat stayed surface in the exploded boiler of H. M. S. Thunderer. It is by no means clear that we know as much as is desirable about structures in which the stays are spaced further apart than 4in. or 5 in.; indeed, all that was known on the subject until the other day may be expressed in very few words. Stay bolts $\frac{3}{4}$in. in diameter, with enlarged ends—a form which gives the best results—may be depended on to stand the following strains: Copper stays, screwed and riveted into copper, 7 tons; iron into copper, screwed and riveted, will stand 10 tons; iron stays only screwed into copper will bear 8 tons; while iron stays screwed and riveted into iron plates will support 12 tons. In applying these facts in practice we have but to consider how many inches of surface multiplied by the pressure per inch which the boiler will have to bear, will give the permissible strain. For example, the side of a fire-box made up with iron stays $\frac{3}{4}$in. diameter, screwed and riveted into a copper plate may be considered safe with a strain of 2 tons on each stay. If the working pressure be 140 lbs. on the square inch, then each stay may be supposed to support $\frac{4480}{140} = 32$ square inches. Such stays might, therefore, be spaced 5.65in., or say $5\frac{1}{2}$in. asunder. If spaced 4in. asunder the strain on each stay will be only one-tenth of that at which it would give way. Experiments made by Fairbairn, however, go to show that the strength of surfaces closely stayed is much greater than may be deduced from the respective areas of the surfaces supported; because, when the stays are far apart, the plate between them bends, though the stays will not give way, and the holes through which the stays pass become distorted, and so the stays slip through. Thus in the experiments to which we have just alluded, it was found that flat surfaces stayed at 5in. apart gave way when the strain on each stay reached 9 tons, while with 4in. spaces, everything else remaining as before, the strength of each stay reach $11\frac{1}{2}$ tons. Stay bolts spaced far asunder, as in marine boiler work, give somewhat different results. Within reasonable limits the power of resistance of $1\frac{1}{4}$in. stays screwed and riveted into iron plate, varies as the square of the thickness of the plates, the yielding point being reached with $\frac{7}{16}$ in. plates at $11\frac{1}{4}$ tons, and with $\frac{1}{2}$in. plates at $14\frac{3}{4}$ tons. Mr. D. K. Clark gives a rule laid down by Mr. W. Bury for finding the working pressure in marine boilers, which is to the effect that 112 times the square of the thickness of the plate in sixteenths of an inch, divided by the area of stayed surface in square inches per stay, equals the working pressure.

The United States Government, dissatisfied with the meager amount of information existing on this subject, the gist of which we have just given, gave instructions last year to Messrs. Sprague and Tower, naval engineers, to carry out a series of "experiments to determine the value and resistance of screw stay bolts for boilers under different conditions, using iron, steel, and copper of different thicknesses." We have already referred to the report prepared in accordance with this order as being imperfect. "Want of time prevents the discussion of the matter as fully as desirable," write Messrs. Sprague and Tower; but want of time did not prevent them from preparing a multitude of tables of results, and we much regret that they did not—time being it appears of importance—cut their experiments short, and discuss their results as they ought to be discussed. The report appears in the form of an appendix to the last "Annual Report of the Chief of the Bureau of Steam Engineering for 1879." The apparatus used consisted of a ring of gunmetal, 4in. deep and 18in. internal, and 23in. external diameter, faced on both sides, and provided with thirty-one holes, through which bolts passed to secure the plates to be tested. All the experimental plates were cut to the outer diameter of the ring, made quite flat, and the stay bolt holes drilled. The stay bolts, after the first few experiments, were all secured by inside and outside nuts in a thick back plate. The thin front plate was the experimental plate. The results obtained may. to a certain extent, be

summarized; they cannot be completely and properly dealt with by any one but Messrs. Sprague and Tower. 1in. bolts not riveted, but only screwed into ½in. iron plates, were pulled through the plate with a strain of 9.3 tons; 1in. bolts riveted with an ordinary low conical head, three threads being left for riveting, drew with a strain of 11 tons; 1in. bolts with a button head rivet made with a snap, a length of bolt equal to seven-sixteenths of its diameter being left for riveting, stood 15.1 tons before giving way; while a 1¼in. bolt, snap riveted, a length of bolt equal to half its diameter being left for the purpose, stood 17.3 tons. All these stays were spaced 4in. from center to center. When the distance was augmented to 5in., other things remaining the same, the strains supported were 9.8 tons, 14 tons, and 15.5 tons. If we compare these figures, it will be seen that the form and dimensions of the rivet head exercise a most important influence, good shape and size augmenting the strength of each stay from 9.3 tons for an unriveted stay to as much as 15.1 tons for stays properly riveted. No experiments made in this country have served to demonstrate this important circumstance. If, again, we compare the figures we have given with those obtained by Fairbairn, we shall find some points worthy of note. The best result obtained by Fairbairn was with ⅝in. stays, screwed and riveted into a ⅝in. plate. These bore a strain of 12.5 tons before failure. The sectional area of such a stay is .4417 square inch, while that of a 1in. stay is .7854in. If the power of resistance of the stays varied as their sections, then a 1in. stay should have stood over 22 tons; but as this contemplates a tensile strength in the iron of which the stay was made of over 28 tons on the square inch, it is tolerably clear that under the conditions the stay would have snapped before it pulled through the plate. We may compare the American experiments with those made by Mr. Phillips in Plymouth Dockyard, when 1⅝in. bolts in ½in. plates stood but 14.73 tons—say 15 tons. But the sectional area of these bolts was to that of the American bolts as 1.448 is to .7854, or very nearly two to one. From this it appears that nothing is to be gained by augmenting the diameter of a stay bolt unless the thickness of the plate is augmented at the same time; and it may be taken for granted that a stay bolt whose diameter is twice as great as the thickness of the plate is as thick as it can be made with advantage, probably a little thicker. We are now dealing, of course, with comparatively thin plates. Concerning the strength of stayed surfaces of plates ¾in. thick or upwards, nothing is thoroughly known.

The experiments of Messrs. Sprague and Tower were fortunately extended to steel. We have not space to give particulars of the tests. It must suffice to say that in comparing the results of three different thicknesses, in each case —½in., ⅝in., ¾in. plate—of iron plates and iron bolts, steel plates and iron bolts, steel plates and steel bolts, the diameter of the bolts being 1in., 1⅛in., and 1¼in., their distance apart and conditions of trial being the same, it wa found that in the case of the iron plates and iron bolts the strain required to draw the bolts through the plates was equal to 74.77 per cent. of the tensile strength of the bolt; with the steel plates and iron bolts 77.36 per cent.; and with the steel plates and steel bolts 85.44 per cent. The tensile strength of the Otis steel stay bolts was but little over 19 tons on the square inch, or as nearly as possible that of the iron bolts used; and the steel was as soft as Low-moor iron, to judge from the statements made concerning the ease with which it was riveted. We have no information concerning the strength of the Otis plates, but we may take it for granted that they closely resembled the bolts. In nearly if not all cases the failure of the steel bolts began with the splitting of the rivet heads of some of the central stays; and it is extremely probable that if a harder steel had been used the resistance of the stays would have been much increased. We may remark before concluding that information is much needed concerning the behavior of steel stayed structures. Experiments in this direction cannot be much longer postponed. They need not be elaborate, nor very costly, and the ground being to all intents and purposes untrodden, any practical engineer with sufficient time at his disposal could obtain a great deal of valuable information. This is a line of

experiment which we commend to the Research Committee of the Institution of Mechanical Engineers. It is to be hoped that the United States Government, which deserves no small thanks, first for carrying out useful practical inquiries, and then giving the results to the world, may see fit to extend the investigations of Messrs. Sprague and Tower, who appear to be highly competent men, to steel such as we are accustomed to use in this country. The Otis, so-called "steel" appears to be more a peculiarly fine and homogeneous iron than anything else. It certainly would hardly be regarded as a steel in England.

DR. SIEMENS' NEWEST ELECTRICAL RESULTS.—A paper was read on Thursday night before a crowded meeting of the Society of Telegraphic Engineers by Dr. Siemens, F. R. S., upon "Recent Applications of the Dynamo-Electric Current to Metallurgy, Horticulture and the Transmission of Power." The President, Mr. W. H. Preece, was in the chair. In his paper Dr. Siemens said that he was prepared to corroborate a statement which he had made on a previous occasion, affirming the applicability of the dynamo-electric current to hitherto unaccustomed purposes. Among these purposes was the transmission of power, and the accomplishment of large chemical results, such as the decomposition of metallic salts. The electric arc was capable of producing intense heat with a moderate expenditure of energy, and of effecting the fusion of platinum or steel. Amidst loud applause, Dr. Siemens personally illustrated this by the experiment of melting two quantities of steel in a plumbago crucible, the first being fused within a quarter of an hour, and the second within the short space of eight minutes. In describing the effect of the electric arc upon horticulture, Dr. Siemens related the result of some experiments he had made in this direction. They went to prove that the electric light was efficacious in ripening fruit, and if this should be confirmed, the horticulturist would become independent of solar light in producing a high quality of fruit at all seasons of the year. With regard to the application of the dynamo-electric current to mechanical propulsion, Dr. Siemens gave details of a practical trial which had been made in Berlin of a toy railway upon this system.

REPORTS OF ENGINEERING SOCIETIES.

SOCIETY OF ENGINEERS.—At a meeting of the Society of Engineers, held on Monday evening, June 7th, in the Society's Hall, Victoria Street, Westminster, Mr. Joseph Bernays, President, in the chair, a paper was read by Mr. Arthur Rigg, engineer, of 1 Fenchurch Street, London, E. C, on "Sensitiveness and Isochronism in Governors." As the attainment of a regular rate of speed is the only object of a governor, it is an interesting inquiry how far this result is achieved by the sensitive and isochronous governors, now frequently applied to steam engines. The irregular manner in which power is communicated from a piston to a crank causes periodical variations in speed, which vary greatly in their degree, between such classes of steam engine as the common agricultural type and the high class mill engine. Whenever there is great sensitiveness in a governor, it is often found that inherent irregularities in speed tell to such an extent that the governor becomes uncertain, runs from one extreme of its range to another, and produces hopeless confusion in the speed of the engine it was intended to regulate—giving, in fact, a worse result, than would be produced by a governor of the common type. This evil has been remedied by retarding the movement of sensitive governors, causing their movement to force fluids through small orifices, an unreliable method now superseded by a method invented by the author, whereby the balls overcome the inertia of a mass of metal as they move in or out, a plan applicable to the usual type of governors, and also to those which are direct-acting, fixed upon an engine shaft and altering the stroke of an expansion eccentric. Thus, such governors may be made to effect a more uniform regulation than has hitherto been attainable, and their extreme simplicity remains without attendant disadvantages. An illustration of the relay system was given, where the governor moves a valve, admitting hydraulic pressure under a plunger to raise or lower the sluice of a turbine, and so regulate its rate of motion. It was finally shown that governor and engine should correspond in their relations so as to work harmoniously together; and that perfect regularity is unattainable, and can only be approached by providing sufficient inertia in the moving parts to diminish the effect of irregularities in power or resistance until the governor can operate; and that a high rate of revolution attains this condition with the greatest economy and success; and that although the governor may advantageously approach isochronism, its sensitiveness must not be excessive.

IRON AND STEL NOTES.

REPORT ON THE RESULTS OBTAINED BY TESTING STEEL RAILS AT NATURAL AND ARTIFICIALLY LOWERED TEMPERATURES.—One of the most important questions under con-

sideration in elaborating the technical conditions for steel rails ordered by the Russian Government from native works, with the view of creating in Russia the manufacture of rails, was the following: How to ensure a hard rail—*i. e.*, containing a high percentage of carbon and phosphorus—which will stand the test in the summer at a warm temperature, without being too brittle for wear in the cold winter time, and whether, by freezing, those rails should stand the same tests as when tested at a warm temperature. With the view of obtaining some guarantee in this respect, it was proposed, firstly, to increase the severity of the tests during the summer time; secondly, to prescribe certain limited percentages of carbon and phosphorus in the steel; thirdly, to manufacture rail steel with determined materials, in accordance with samples adopted by the Ministry. These conditions were, however, each of them difficult to carry out in practice, and could only be controlled with difficulty. It then occurred to the director of the Railway Department, Mr. D. J. Jouraffsky, that the desired object might be attained by placing the rail in the summer-time under the same conditions as in the winter, viz., to test the rails in the summer at artificially lowered temperatures. Trials made immediately, in accordance with this idea, proved that the plan could be very easily worked out, and by very cheap and simple means. It was found that by placing pieces of rail 6ft. to 8ft. long in a mixture of ice and salt, the temperature of the rail could be lowered in a very short space of time, during warm weather, to 20 deg. below freezing point Celsius. In order to work out this question to the fullest extent, a special commission, composed of the following engineers, viz, Messrs. Erakoff, Beck, Guerhard, Nicolai, and Feodossieff, was appointed to carry out a series of tests on this plan with rails from different works. The commission fulfilled its task in the following manner: From seven works, viz., those of Cammell & Co., John Brown & Co., Brown, Bailey and Dixon, Creusot, Cockerill, Terre Noire, Pontiloff, and Baird—the latter two Russian works—pieces of rail six ft. long were taken, one of which was tested at the natural temperature, the others being placed in a box filled with a mixture of two parts of small ice and one part of salt, and, after arriving at a temperature of from 16 deg. to 21 deg., which occurred in half an hour, they were submitted to the same tests as the first piece. Small test bars were taken from the same rails to try the tensile strength, and filings were also taken for analysis. The results obtained from all the trials were given in a table, which, for the reasons given below, we do not reproduce, and they have confirmed the idea that the brittleness of the steel increases very much at low temperatures, if it contains more than a certain limit of phosphorus, silicon, and carbon. By examining the tables of the trials, in which the eighty-six samples are divided into two groups, viz., (*a*) rails which broke under the tests, and (*b*) rails which stood the test, we arrive at the following facts: The total of the three elements named in the rails which broke under the test averages 0.54 per cent., and in those which stood the same test 0.41 per cent.; the first total—0.54 per cent.—varying from 0.44 to 0.67 per cent., and the second total—0.41 per cent.—varying from 0.37 to 0.55 per cent. But it is ascertained that the three elements, carbon, phosphorus, and silicon, have not the same influence upon the hardness of the steel. Phosphorus is supposed to have the greatest influence, then silicon, and lastly carbon. The total of the three hardening elements expressed in Dudley's phosphorus units were, for rails which stood the test, 19 units; for rails which broke under the same test, 31 units. In the first the units vary from 16 to 22 in one case only 25 being reached; and in the second the difference was from 22—and that only in two cases, all the others being higher—to 45 units. —*Engineer.*

NITROGEN IN STEEL.—As regards the presence of nitrogen in ingots of pig iron and steel—often in very notable quantity—I will venture upon the following explanation. When an ingot of liquid steel solidifies, it passes from the density of about 6.60 to that of 7.90. A pocket or cavity (*poche de retassement*) is formed, the metal of which has gone to feed other parts of the solid, and during the solidification, no matter what care may be taken to cover in the ingot; as the metal is pervious to gas the air finds its way into the cavity, oxygen is absorbed by the iron, and the reddish color of the walls of the cavity, which are often crystalline, is, in fact, due to oxidation; the nitrogen meanwhile remains imprisoned. It is thus that in some bars of rolled steel it has been proved that ammonia was given off abundantly from a certain point in the bar, probably corresponding with the previously mentioned cavity of the original ingot. There is nothing anomalous in the idea that nitrogen and hydrogen under pressure should combine to form ammonia. This question of the presence of ammonia in steels has been solved, either affirmatively or negatively, by a great many impartial observers.

It is quite permissible to believe that those persons who deny the presence of this gas failed to discover any in the bars of steel on which they operated, and, on the other hand, that those who affirm it really detected its presence. It may, therefore, be supposed that ammonia occurs more especially in steels high in manganese, which have the property of dissolving hydrogen gas, and of absorbing it even at a cherry red heat (800° Cent.), and that it exists, not uniformly distributed, but localized in certain parts of the test bar. Soft steels, with 0.1 per cent. to 0.2 per cent. of manganese, or hard steels high in carbon, would give off little or no ammonia. The explanation I have hazarded is only applicable to determinations of large quantities of nitrogen made on cast ingots of pig metal or steel; but not on isolated bars of small dimensions. Nitrogen, in fact, present in all steels and in all pig irons, only occurs in very small proportion of the total gases therein contained, as was demonstrated by M. Boussingault and Colonel Caron in their discussion with M. Frémy some twenty years

ago.—*M. Pourcel's paper before the Société de l'Industrie Minérale.*

THE difficulty of rendering small steel and iron articles bright, by removing the "scale," or coating of oxide, may—the *Electro-Metallurgist* says—be readily overcome by the following process, without having recourse to the ordinary method of scouring, after pickling with dilute sulphuric acid. First, let the articles be plunged into a boiling solution of caustic potash or soda for a few minutes, to remove greasy matter, then rinse in clean water. Now place the articles in a weak pickle of sulphuric acid—about half a pound of acid to each gallon of water. From ten to twenty minutes' immersion is generally sufficient to loosen the scale or oxide. If the scale be sufficiently loosened, it will readily yield to the touch of the finger. Let the articles be again rinsed, and afterwards dipped, by means of a perforated stoneware basket, into a strong solution of commercial nitric acid for an instant, when the black scale will be immediately removed. The dipping basket should have a rotary motion given to it while in the acid, and then removed promptly and plunged into cold water. The articles may then be coppered, silvered or gilt with ease.

LARGE STEEL PRODUCT.—The Scranton Steel Works made in twenty-four hours, Wednesday, December 10, 466 tons 12 cwt. of ingots. The steel works also made last week their largest week's work to date, 2,415 tons 7 cwt. of ingots, beating their largest previous work by 62 tons.

The steel rail mill rolled last Wednesday 736 bars in ten hours fifty minutes; average time per bar, fifty-three seconds; and Wednesday night 800 bars in eleven hours ten minutes; average time per bar, fifty and a half seconds—a total of 1,536 bars in twenty-two hours, which, it is claimed, has never yet been beaten on any rail train in the world. The largest previous recorded output was 1,044 bars in twenty-four hours, made at Harrisburg in 1877.

The rail mill also rolled last week 1,877 tons 15 cwt. of rails; this being the largest week's work ever yet recorded on any one rail train, either in Europe or America. Largest previous work was at Harrisburg—1,617 tons, in November, 1877. We will also call the attention of our Lehigh friends to the fact that No. 1 Furnace of the Lackawanna Iron and Coal Company has, during the last fourteen weeks, made the extraordinary average of 544 tons weekly, and their Franklin Furnace, during the same time, 478½ tons weekly.—*Scranton (Pa.) Republican.*

RAILWAY NOTES

ITALIAN TRAMWAYS.—Tramways have now been established in twenty-four cities and towns in Italy, the aggregate length of the lines at the end of 1879 being 320 miles, of which no less than 219 miles are worked by mechanical power, the remaining 101 miles employing horse traction. In addition to the lines already at work there were at the end of last year 89½ miles in course of construction, and no less than 626 miles projected, it being intended that 611½ miles of these projected lines should be worked by steam power or other mechanical means. Altogether steam worked tram lines for suburban traffic are coming decidedly into power in Italy.

THE railway at Vesuvius was opened this week. The line is 860 metres in length, and from the station at the summit a winding path leads to the edge of the crater. The *Times* correspondent writes: "It is not a train in which one travels, but a single carriage, carrying ten persons only, and as the ascending carriage starts another, counterbalancing it, comes down from the summit, the weight of each being five tons. The carriages are so constructed that, rising or descending, the passenger sits on a level plane, and whatever emotion or hesitation may be felt on starting, changes, before one has risen 20 metres, into a feeling of perfect security."

AT a recent meeting of the Franklin Institute, Mr. W. Barnef Le Van read a paper on "High Railway Speeds," suggested by the trial trip of the locomotive built at the Baldwin Locomotive Works for the Reading Railroad Company, and intended to run from Philadelphia to New York in 90 minutes, or at the rate of a mile minute. To do this it must be capable of running at a faster rate on parts of the road to make up for time lost in passing over bridges and through towns, where a slower rate is necessary. To accomplish this with safety the road bed must be in perfect condition, and some changes must be made in the form of locomotives as now commonly used. This new locomotive has a single pair of driving wheels 6½ feet in diameter, in place of coupled drivers of 5½ feet in diameter. In the latter form of engines run at high speed there is danger that the coupling rods connecting the driving wheels will be broken by centrifugal force. The larger wheel also reduces the number of revolutions per mile of run. In the new locomotive the boiler has 1400 square feet of heating surface and about 56 square feet of grate surface. The dimensions are as follows: Diameter of cylinder, 18 inches; length of stroke, 24 inches; diameter of driving wheel, 78 inches; wheel base, 21 feet 1 inch; distance from centre of driving wheel to centre of trailing wheel, 8 feet. The boiler is made of $\frac{7}{16}$ inch steel and is 52 inches in diameter. It contains 198 tubes 2 inches in diameter and 12 feet 2¾ inches long. The fire box is 96¼ by 84 inches. The capacity of the tender is about 3,800 gallons of water, and weight when filled with water and coal, 70,000 pounds. The weight of the engine is 85,000 lbs., and is so disposed that by an alteration of fulcrum points additional weight can be thrown on the drivers at the time of starting. At a trial trip on May 14th, the engine was attached to a train of four cars, each weighing about 42,000 pounds, making the weight of the train complete, about 148 tons. The run was made at rates ranging from 27 miles an hour, between Ninth and Green and Wayne stations, to 62 miles an hour, between Trenton Junction and Bound Brook, the time from Ninth and

Green to Jersey City (89.4 miles) being 98 minutes, or at the rate of 54⅔ miles per hour. On the return trip the run was made in 100 minutes In a former trip the engine developed a speed of nearly seventy-nine miles an hour. In these trial trips the engine consumed 36 gallons or 300 pounds of water per minute. Mr. Le Van prophesied that within five years "passengers would be set down in New York in New York in one hour's time from this city." The average time on English railways is 46 miles per hour, on French 37½, on German 40, and on American 37. On English railways, 6½ feet driving wheels are quite as common as 5½ wheels, and some of the fast lines have 8 and 9 feet wheels, one line having 10 feet wheels. Engines with one pair of drivers are not new in this country, and Mr. Le Van described several which had been built at the Baldwin Locomotive Works, by Edward S. Norris and Norris Brothers, and by Ross Winans, of Baltimore. Some of these developed high rates of speed.

THE number of passengers killed in accidents on the railways of Prussia in 1878 was twelve, while forty-six was the number of the injured. The cause in eight of the fatal and sixteen of the non-fatal cases was imprudence or want of caution on the part of the victims or sufferers themselves in entering or alighting from the carriages. The deaths were only one in every 9½ million passengers, and the cases of injury only one in every 2½ million passengers. This result shows an improvement in regard to the safety of traveling on Prussian lines. The average of five normal years before the last showed that there had been one passenger in every 5⅜ millions killed, and one injured in every 1¼ million passengers. Of the railway servants and officials there was an accident last year to one in every 171, while among the railway laborers there was an accident to one in every 120. There were ninety-three persons who attempted suicide by laying themselves on the line, and eighty-six of these cases were attended with fatal results.

RAILWAY STATISTICS.—Since 1875, some 10,268 miles have been built in Europe, and about 5,000 miles in other parts of the world outside of the United States, chiefly in Australia and India, so that the world's railways probably stand to-day as follows:

Europe	98,275 miles,	or 47	per cent.
United States....	86,121 "	41	"
Rest of the world	25,000 "	12	"
	209,396		

Thus our 50 millions of inhabitants have furnished themselves with 86,000 miles of railway, while the 306 millions of Europe have 98,000 miles, and the 1,050 millions of the rest of the world possess but 25,000 miles.

There was in Great Britain on the 1st of January, 1879, 17,333 miles of railway, on which there were about 32,000 miles of track, 12,969 locomotives, 418,322 passenger and freight cars, owned by the companies, in addition to some owned by private parties, and over which trains ran 222,376,114 miles, and conveyed 565,000,000 passengers.

The capital account of the English roads was 698,545,154 pounds sterling, or $3,380,958,545, thus giving an average cost of $195,059 per mile of road.

The average cost per mile in several other countries about the year 1875, was as follows:

France	1873	$152,500
Belgium.....	1873	111,342
Germany.....	1875	100,570
Austria-Hungary	1875	105,847
All Europe.....	1875	120,960
United States...	1879	58,915

Thus our railroads have cost less than half as much per mile as those of Europe.

Going back one year, for purposes of comparison, on the 1st day of January, 1879, we had in the United States, 81,841 miles of railroad, on which there were 101,660 miles of track, or enough to encircle the globe three and a half times. There ran upon these roads 16,445 locomotives, 11,683 passenger cars, 4,413 baggage, mail and express cars, and 423,013 freight cars.

The capital invested was $4,772,297,349, or $58,915 per mile of railroad; the gross earnings were $490,103,351, or $6,200.52 per mile; the working expenses were 61.79 per cent. of earnings, or $302,528,184—say $3,887.10 per mile of railroad; and the net earnings were $187,575,167—say $2,322.42 per mile, or 3.932 per cent. on the nominal capital.

While the greater cheapness of our American railroads is in some measure due to the comparative smoothness of much of our country, and to the absence of heavy land damages, much more is due to the methods of construction applied to the railroads themselves, to the cheap and efficient expedients which our engineers have introduced, and especially to the character of the rolling stock which we have adopted.

The early locomotives obtained an adhesion and tractile power equal to $\frac{1}{4}$ of the weight upon their driving wheels. I believe that in other countries $\frac{1}{5}$ of the weight is even now considered a standard and satisfactory performance, while our American locomotives, including the latest type, the "Consolidation" engine, of 50 tons weight, regularly work up to $\frac{1}{6}$ in winter, and $\frac{1}{4.5}$ in summer, of the weight upon their drivers, with occasional performance up to $\frac{1}{4}$, and even less.

That is to say, if a locomotive has 88,000 pounds weight upon eight driving wheels, and obtains an adhesion of $\frac{1}{5}$, it will pull a train equal in resistance to the lifting of a weight of 12,571 pounds; while if it works up to $\frac{1}{4.5}$ in adhesion, it would pull 19,555 pounds, or 55 per cent. more under the same circumstances.

Not only do our locomotives pull greater trains than do European locomotives, in proportion to their own weight, but they run more miles in the course of the year; Stürmer's statistics for 1875, showing that the average train mileage for locomotives (not the engine mileage, but the mileage of passenger and freight trains, divided by the whole number

of locomotives), was for all Europe, 15,720 miles per year, and for the United States, 21,900 miles per annum.

This has been accomplished by a series of improvements in construction, which have brought our locomotives materially to differ from their European prototypes, and which fairly entitle us to speak of them as American in design.—[*Abstract of Mr. Chanute's address at the Convention in St. Louis.*

A TABLE constructed by Professor Stürmer, of Bromberg, shows the length of railway in several of the chief countries of the world, and its proportion to the population. In Europe, on the average, there are 4.9 kilometers of railway to every 10,000 inhabitants. Greece has the least proportion to the population, having only 0.08 kilometer to every 10,000 of the population. Next comes Turkey, with 1.6; Portugal, 2.3; Roumania, 2.4; Russia, 2.8; Italy, 2.9; and so upward in the scale, France having 6.3; Germany, 7.1; Great Britain, 8.1; and Sweden heading the list with 10.8, though its total mileage is not a fifth of that of Great Britain. In Asia it appears that only 0.16 kilometer is averaged to every 10,000 inhabitants; and in Africa the proportion is only 0.17. In the United States the proportion is heavy—32.9 to every 10,000 of the people; while the whole of America has the average of 17.2, and in Australia the proportion is already 10.6.

ENGINEERING STRUCTURES.

THE HUDSON TUNNEL.—This work is already well under way. Beginning in Jersey City, a shaft at the foot of Fifteenth St. has been sunk to the depth of sixty feet. From the foot of this shaft, which is provided with an air-lock, the tunnel is being worked towards the river. The exterior structure or shell of the tunnel consists of a cylinder of one-half inch boiler-plate iron, with a lining of brick two feet thick securely anchored to it. The river on the line of the tunnel is about 5,500 feet in width, and its bed is largely composed of blue clay, with a mixture of sand and other substances.

The excavation is begun at the top, and carried forward in sections. The plates of which the iron casing is composed are placed in position as fast as sufficient space is excavated. These plates are two and one-half feet in width by three and six feet in length. They are bolted together by means of angle-iron secured to their edges. The brick-work is laid as rapidly as a circle of sections is completed. The silt is thrown back into a pool, into which is running a stream of water forced in from a pump in the shaft by the pressure of the condensed air in the tunnel. This water, carrying about one-half of the silt, is blown out through a six inch pipe into the receiving tank. The remaining portion is carried into the finished tunnel.

The office is connected with the tunnel by telephone, and the electric light is used both in and out of the tunnel, work being carried on throughout the 24 hours. An average of about 4 feet of the tunnel is finished daily.

The top of the tunnel will have an average distance of about twenty five feet below the river bed. This makes necessary a considerable grade, as the river at some points reaches the depth of 60 feet.

The entrance to the tunnel on the New Jersey side will be at a point about three-quarters of a mile from the river. The terminus in New York has not been settled, but the tunnel will enter the city at the foot of Leroy St. An underground depot will be used, and nowhere will the track be less than fifteen feet below the surface. The approaches on either side will be 26 feet in width and 24 feet in height, with a double track; but under the river there will be two tunnels, side by side, each 18 feet in height and 16 feet in width, and each containing a single track. Work is now in progress in only one of these tunnels, but everything is in readiness to begin the adjoining one soon, when operations can be begun on the New York side also. With approved facilities it is expected that each section will be advanced at a rate of five feet per day.

WATER SUPPLY OF ADELAIDE (S. A.)—The total quantity of water supplied to Adelaide, South Australia, from the Hope Valley and Thornton Park reservoirs during January was 81,000,000 gallons. The average daily consumption was, therefore, 2,600,000 gallons. The consumption of water varied very much on different days, the variation being partly, but not wholly, due to fluctuations of temperature. It is curious to note that in each week the greatest consumption of water took place on either Tuesday or Wednesday, whilst Friday or Saturday generally were the days on which the demand was the least. The greatest consumption on any one day during the past summer took place on Tuesday, January 13, when 5,120,000 gallons were used; on Wednesday, January 21, there were used 4,070,000 gallons; and on Wednesday, January 28, 4,370,000 gallons. A large amount of work has been lately done by the South Australian Water Works Department, in laying new mains, and but for the activity thus displayed it would have been impossible to maintain the supply of the whole area as effectively as has been done. An idea of the magnitude of the system can be gathered from the fact that the Adelaide water area now comprises 100 square miles of country.—*Engineering.*

DURING the past week the first practical steps have been taken towards realizing another gigantic work of Alpine railway engineering, namely, the Arlberg Railway tunnel. The project will occupy several years in executing, and when complete will worthily rank with the tunnels already in existence through Mount Cenis and the St. Gothard. The work just commenced will open direct railway communication between Austria and Switzerland, and thus provide a direct route between Austria and France without passing, as has hitherto been necessary, through the States of Southern Germany. The operations of the engineers and surveyors during the past few days have been directed mainly towards finally determining the axis of the new tunnel.

THE CHANNEL TUNNEL.—According to the *France*, the preliminary workings for the tunnel uniting England and France have had the most satisfactory results. The promoters have sunk their shaft to the stratum in which they propose to bore the tunnel, and are now going to sink another shaft and lower all the machinery for the bore. In eighteen months they expect to have reached two kilometers under the Channel, and in three or four years to have completed the task.

THE proposed canal from Bordeaux to Narbonne has been reported on by M. Lepinay, and is not unlikely to be carried out. It will be about 250 miles long, the locks allowing the passage of vessels over 400 feet in length. The surface breadth in the narrowest parts will be 184 feet, but for forty-five per cent. of the whole length the canal will be double and 262 feet wide. It is calculated that ordinary cargo steamers will save four days in the voyage from Brest to Malta.

WORK on the new Eddystone Lighthouse is progressing rapidly. Two-thirds of the solid base is now brought up to within three feet of high water spring tide, and by the end of the week the rock base will be entirely covered with the stepped courses of masonry. By the end of the season the work will be far less dependent on the weather.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

MONTHLY REPORT OF THE WEATHER BUREAU for June.

Minutes of Proceedings of The Institution of Civil Engineers:

"Fixed and Movable Weirs.' By Leveson Francis Vernon Harcourt, M. A.; also "Movable Dams in Indian Weirs." By Robt. Burton Buckley, A. M. I. C. E.

Annual Report upon the Survey of Northern and Northwestern Lakes and the Mississippi River. In charge of C. B. Comstock, Major of Engineers, and Brevet Brigadier General U. S. A., Washington Government Printing Office.

SEWERS AND DRAINS FOR POPULOUS DISTRICTS. By JULIUS W. ADAMS, Chief Engineer of the Board of City Works, and Consulting Engineer to the Board of Health, Brooklyn. New York: D. Van Nostrand. London: Trübner & Co., Ludgate Hill. Price, $2.50.

The whole question of sewerage for towns has been ably and exhaustively discussed by Mr. Adams, in a volume bearing the above title, and as the London main drainage system has been taken as the basis of the work, it will be quite as acceptable to the sanitary engineers of this country as to those of the United States. In 1857 Mr. Adams was charged with the preparation of plans for the sewering of the City of Brooklyn, covering an area of 20 square miles, much of which was then suburban territory. At that date no gaugings had ever been made of the discharge of sewers, and the only principle recognized was to make the sewers large enough to admit a workman to clean them by the use of shovel and pick. In 1852 the General Board of Health under the Public Health Act made their first report to the British Parliament, and advocated very strongly the introduction of smaller pipes in lieu of the large brick and stone drains heretofore in use for house drainage. The tables appended to the report, however, suggested the use of pipes, which experience proved to be unquestionably too small, so that they became less and less recognized as a standard, until some seven years since they were to some extent replaced by the suggestions of a private English engineer, whose views have in their turn been proved to be quite as erroneous in the other direction. The principle laid down in the Hydraulic Tables of Neville, which is, no doubt, the correct one, has been generally overlooked, and the value of Mr. Adams's book is much enhanced by the fact that it embodies the principle and practice of sewering towns as illustrated in the working of the Brooklyn system, which is based upon the recognition of Neville's principle.

In devising a system of sewerage for a populous district there are, as Mr. Adams points out, several controlling circumstances to be taken into consideration. It would appear at first sight that the first thing to be considered would be the population of the locality. Were the sewers to be confined to the withdrawal of sewage proper from the vicinity of dwellings this would, to a great extent, be the case, but even then the extent of water supply would be a preponderating element in the calculation. If, for instance, the water supply were derived from wells on or near the premises, as in country villages, the amount of sewage would be materially reduced from what might be anticipated were the water for domestic use obtained by the simple act of turning a faucet, and whether the supply of water was intermittent or constant would exercise an important influence on the amount of consumption or waste from dwellings. The sewage from a dwelling differs by an insignificant amount in bulk from the water consumed or wasted. In fact, the water taken into a dwelling for all purposes is the measure of the sewage which leaves it; and a generous water supply, such as is found in most cities supplied by waterworks, would, under proper management, suffice to carry off all excrementitious, or human refuse. But with the sewers confined to this purpose an additional system of drains on a grander scale is called for to remove the storm water which would otherwise flood the premises, and prove the cause not only of present injury and discomfort to the inhabitants, but subsequently objectionable as well on sanitary grounds.

The subject is systematically divided, so that the several points demanding attention may be dealt with separately. The question of area and physical outlines and controlling features of the district to be drained, its geological character, and the depth to which it may be desirable that drainage should extend are firs

considered ; then that of the rainfall in the district, with consideration of the maximum fall of rain in a given interval of time, and the proportion of such storm water as it is proposed to carry off by the sewers ; next the character and extent of the water supply ; and, lastly, the final disposal of the sewage. The volume is amply illustrated throughout, and will prove an invaluable work of reference to sanitary engineers wherever the English language is understood.—*Mining Journal.*

ENGINEERING GEOLOGY. By W. HENRY PENNING, F G. S. London : Bailliere, Tindall & Cox. For sale by D. Van Nostrand. Price, $1.40.

How to make a geological survey a part of any preliminary survey for engineering work is the subject of this little treatise. Of course, a previous knowledge of descriptive and dynamic geology is indispensable. To render such knowledge practically useful to the engineer so that he can intelligently and systematically record the geological phenomena of any given district is the aim of the author.

Part I. treats of "Geological Strata, their Nature and Relations, and their Bearing upon Practical Works." Part II. deals with "Procedure in the Field." Part III. is devoted to "Economics, Materials, Minerals and Metals ; Springs and Water Supply."

The illustrations though not very abundant are exceedingly good.

AN ELEMENTARY TEXT-BOOK OF BOTANY. Translated from the German of DR. K. PRANTL. The Translations revised by S. H. VINES, M. A., F. L. S. Philadelphia : J. B. Lippincott & Co. For sale by D. Van Nostrand. Price, $2.25.

This book seems adapted to hold an intermediate place among our American text books on Botany, being less rudimentary than some in extensive use, and more elementary than the larger works of Wood and Gray.

It is well illustrated and well printed.

WATER ANALYSIS FOR SANITARY PURPOSES, WITH HINTS FOR THE INTERPRETATION OF RESULTS By E. FRANKLAND, F. R. S. London : John Van Voorst. For sale by D. Van Nostrand. Price, $1.00.

This is probably the most compact of all the authoritative guides to the analyst. It presents in a small compass all the reliable processes for the detection of foreign matters in natural waters, whether deleterious or not.

The high reputation of the author will ensure a wide demand for the book.

The subject is presented in two parts ; the first treating of analysis *without* gas apparatus, and part second of analysis by aid of such means.

An ample appendix treats of many interesting collateral subjects, among which are: The Propagation of Epidemic Diseases by Potable Water ; The Improvement of Water by Filtration ; The Constant and Intermittent Systems of Water Supply, etc., etc.

Several illustrations and numerous tables are added to the text, and will prove valuable aids to the student.

A TREATISE ON THE THEORY OF DETERMINANTS AND THEIR APPLICATION IN ANALYSIS AND GEOMETRY. By ROBERT FORSYTH SCOTT, M. A. Cambridge : University Press. For sale by D. Van Nostrand. Price, $3.50.

This book will be welcome to those mathematical students who are desirous of pursuing their labors beyond the courses of our higher institutions.

The object of the Theory of Determinants is thus explained by Professor Sylvester : "It is an algebra upon an algebra ; a calculus which enables us to combine and foretell the results of algebraical operations in the same way as algebra itself enables us to dispense with the performance of the special operations of arithmetic."

Numerous applications are given by the author to lead the student to independent work.

The book is beautifully printed.

A TREATISE ON THE MATHEMATICAL THEORY OF THE MOTION OF FLUIDS. By HORACE LAMB, M. A. Cambridge : University Press. For sale by D. Van Nostrand. Price, $3.00.

This is an octavo volume presenting, in nine chapters : I. The Equations of Motion ; II. Integration of the Equations in Special Cases ; II. Irrotational Motion ; IV. Motion of a Liquid in Two Dimensions ; V. Motions of Solids Through a Liquid ; VI. Vortex Motion ; VII. Waves in Liquids ; VIII. Waves in Air ; IX. Viscosity.

The higher analysis is employed throughout.

A collection of exercises from various authors is given at the end of the volume.

MISCELLANEOUS.

PERIODIC movements of the ground revealed by spirit levels, formed the subject of a paper recently read before the Paris Academy of Sciences, by M. Plantamour. This gives results of a year's observations at Secheron from October, 1878. The east side went down with decreasing temperature until June, there being a pretty exact parallelism between the curves ; then the east rose until the beginning of September, in a much greater proportion than the exterior temperature. From 32.8mm. the greatest depression to the east, on January 15, to the maximum of elevation 19.5mm. on September 8 gives 52.3mm. as the total amplitude of oscillation during the year, or 28.08s. There was generally besides a daily movement, with amplitude on September 5, of 3″.2. The minimum is usually between 6 and 7.45 a. m., the maximum twelve hours later. In the meridian direction, the movements of the ground are much less ; the total amplitude for the year was only 4″.89. They show an unexplained anomaly relative to the movements east and west. The daily movements in the meridian are very rare, irregular and small. It seems, then, that at Secheron there are periodic movements of rise and sinking of the ground, and that, generally, they are determind by the exterior temperature. Perhaps the configuration and nature of the ground have also some influence.

INTERESTING FIGURES which show where the islands and sand-bars in the Mississippi River come from.—From a series of daily observations extending from the early part of February to the latter part of October, 1879, taken at St. Charles, Mo., under the direction of officers of the U. S. engineer corps, it has been ascertained that the average quantity of earthy matter carried in suspension past that point by the Missouri river, between one foot of the bottom and the surface, amounts to 14,858 lbs. per second, or 1,283,731,200 lbs. each twenty-four hours. The matter thus carried along weighs, approximately, 100 lbs. per cubic foot when dry, giving an average of 12,837,312 cubic feet of earth transported each twenty-four hours during the entire year, enough to cover one square mile with a depth of nearly six inches.

During the months of June and July the average quantity, per twenty-four hours, amounted to 47,396,448 cubic feet; enough to cover a square mile with a depth of one foot and eight inches. The maximum quantity observed for any twenty-four hours was on July 3, when it reached the enormous amount of 111,067,200 cubic feet, sufficient to cover a square mile to a depth of four feet. These figures do not take into account the material that is held in suspension within the lowest foot of the depth, or that which is being rolled along the bottom. If these quantities could be ascertained within any reasonable limit of approximation to correctness, there is no doubt but they would show an amount far in excess of that which has already been determined.—T. H. H. in *Missouri Republican*.

THE TAY BRIDGE.—Numerous proposals have been brought forward with the view of solving the all-important problem of how the Tay Bridge is to be put up, and how its safety is to be secured. The latest proposal is by Mr. J. P. Walker, 32 Baker street, Stirling, late of London, who has constructed a model showing how the Tay Bridge could be put in working order at a small expense. The model which he has made only shows one of the center or 250 feet spans. It is not intended to alter the parts of the bridge at present intact, but merely to reconstruct, on a different scale, the part which has given way. The apparent defect of the bridge, as disclosed by the accident in December last, was the construction of the main spans. It is to these Mr. Walker has directed his attention. The columns supporting the ends of each girder are two in number, each being six feet in diameter, and bound together by iron bands. The pillars or columns are each to be ninety-two feet high, or twelve feet above the level of the bridge. The main object of the inventor was to get the 250-feet girders below the center of gravity, and he proposes to accomplish this by means of suspending the girders at either end. To support the girders strong iron bars will be required, but Mr. Walker is confident that there will be no difficulty with this. The bars will rest on top of the columns, and the girders suspended from it by links. Expansion and contraction are thus provided for, and any lateral motion that might occur will not endanger the columns. To increase the strength of the girders, instead of having the network or cross bars as before, it is intended to have vertical rods connecting the top beams with the girders below. The level of the bridge is not interfered with, and Mr. Walker thinks if the law of gravitation had been strictly adhered to at first, the accident would not have taken place.

THE ST. GOTHARD TUNNEL.—Of the workmen hitherto engaged upon the tunnel, whether at the Goschenen or Airolo ends, nearly 500, who were suffering from what is called the tunnel disease, had left by the beginning of the present month, and have gone to seek renewed health in their homes in Italy. On their departure they were presented by the company with gratuities varying from one hundred to two hundred francs each. The only event of note which has recently occurred within the tunnel was the fall of a large mass of rock, on the 6th inst., by which one man was killed, and five more or less seriously wounded.

BY a recent invention paper boxes are made in Boston directly from paper pulp. The boxes are turned out of any size or shape perfectly seamless and of uniform thickness. After drying, the boxes are run through a second machine at the rate of sixty per minute, receiving, under a preseure of 4000 lbs., such embossing as may be necessary. From the time the paper stock is taken from the bales until the perfect box is turned from the machine, manual labor is entirely avoided. By the use of one set of these machines 30,000 boxes can be produced per day, at less than one-third of the lowest market price of hand-made goods, and doing the work of 200 hands.

THE engine of the train engulfed when the Tay Bridge fell has been successfully raised. It has lost the funnel, but otherwise is said to be little damaged. As yet it has not been minutely examined, but it is said to be clear that it had not been reversed.

THERE is reason to believe that the past winter in the Arctic regions has been an exceptionally mild one, and it appears certain that there has been a remarkably early and large break-up of the ice-fields. The American papers think that the Corwin, the vessel about to sail in order to communicate with the Jeannette, and search for a few missing whalers, will find the objects of her search about to pursue their respective voyages.